Cubism - Braque's Bottle and Fishes, Paris c.1910-12

LAr DUNE ND: ArgonCube

DEEP UNDERGROUND NEUTRINO EXPERIMENT

POND^2
FNAL, Dec 2018
James Sinclair, LHEP

The DUNE Near Detector

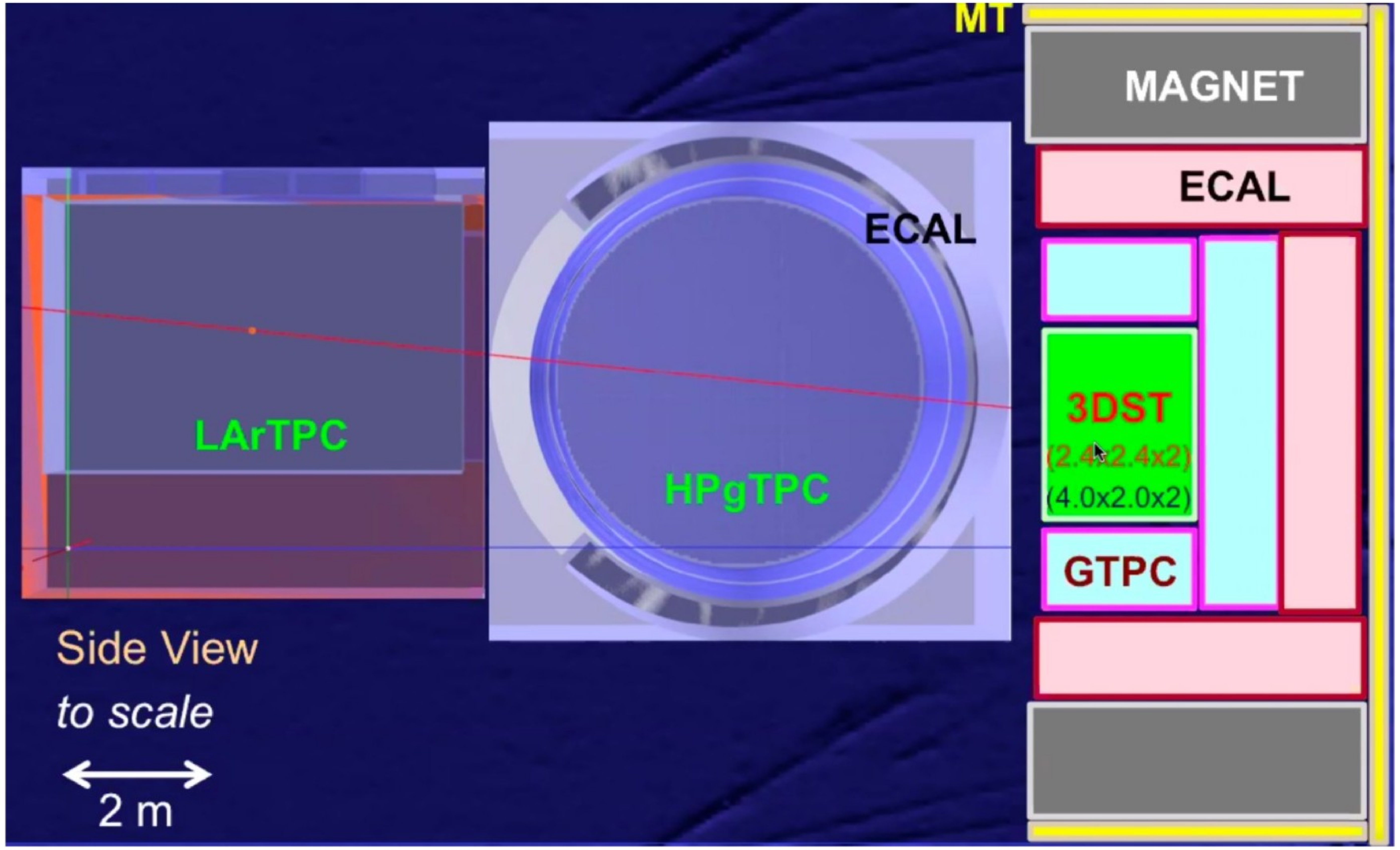


Figure from Clark McGrew

LAr-TPC: high statistics ν-Ar interactions, assessment of LArTPC response.

HP-GArTPC & **3D Scintillator Tracker**: precision characterization of ν-nucleus interactions, complementary signal vs. BG discrimination.

How Much LAr is Needed?

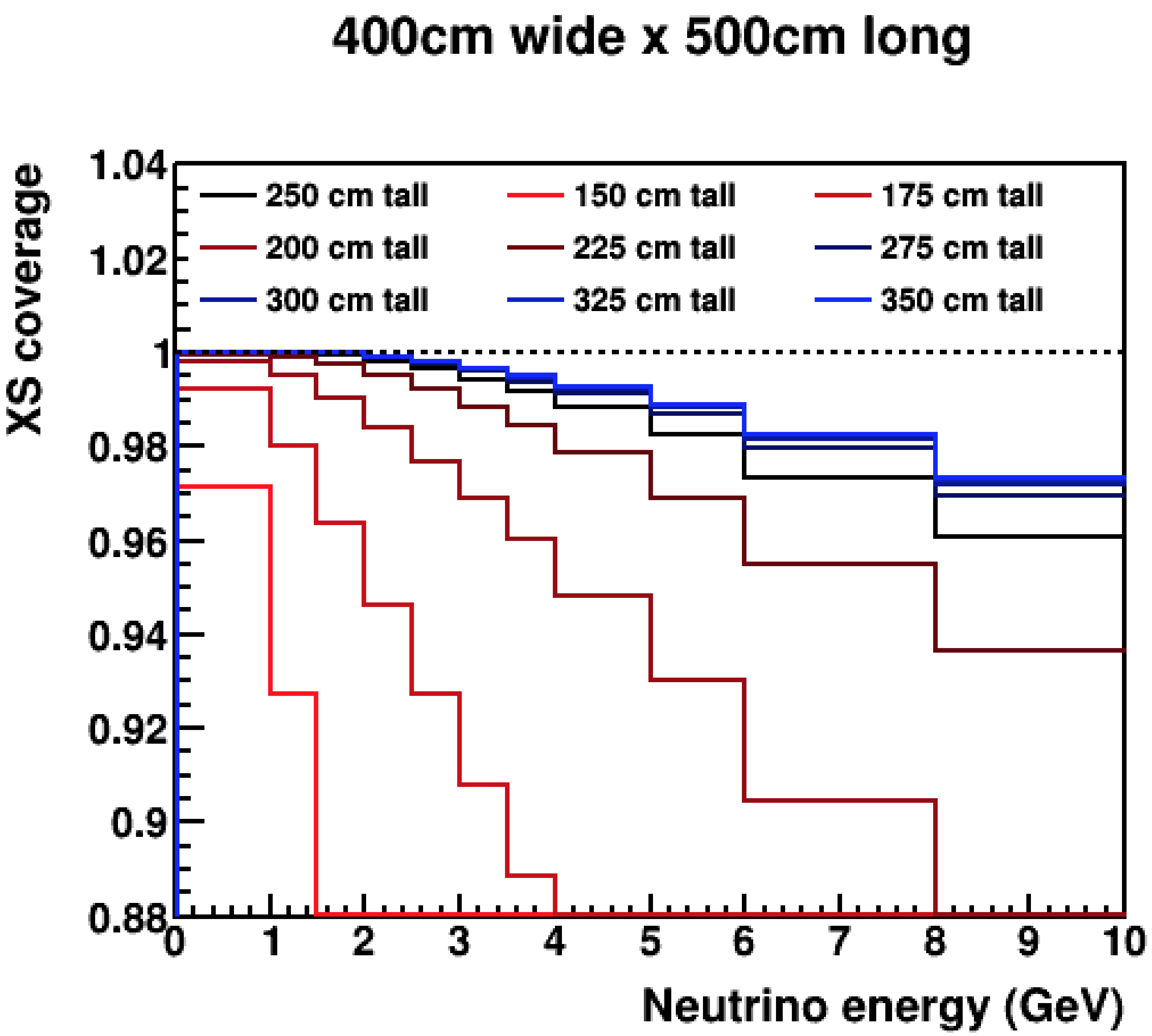
Studies from Chris Marshall.

Optimise for hadronic shower containment.

Reasonable efficiency across a wide range of kinematics, with no phase space that has zero acceptance.

Metric: >95% of energy has to be contained, excluding neutrons.

Optimal dimensions:
- **3 m** tall.
- **5 m** in beam direction.
- **4 m** transverse to beam.



How Much LAr is Needed? - A Little More

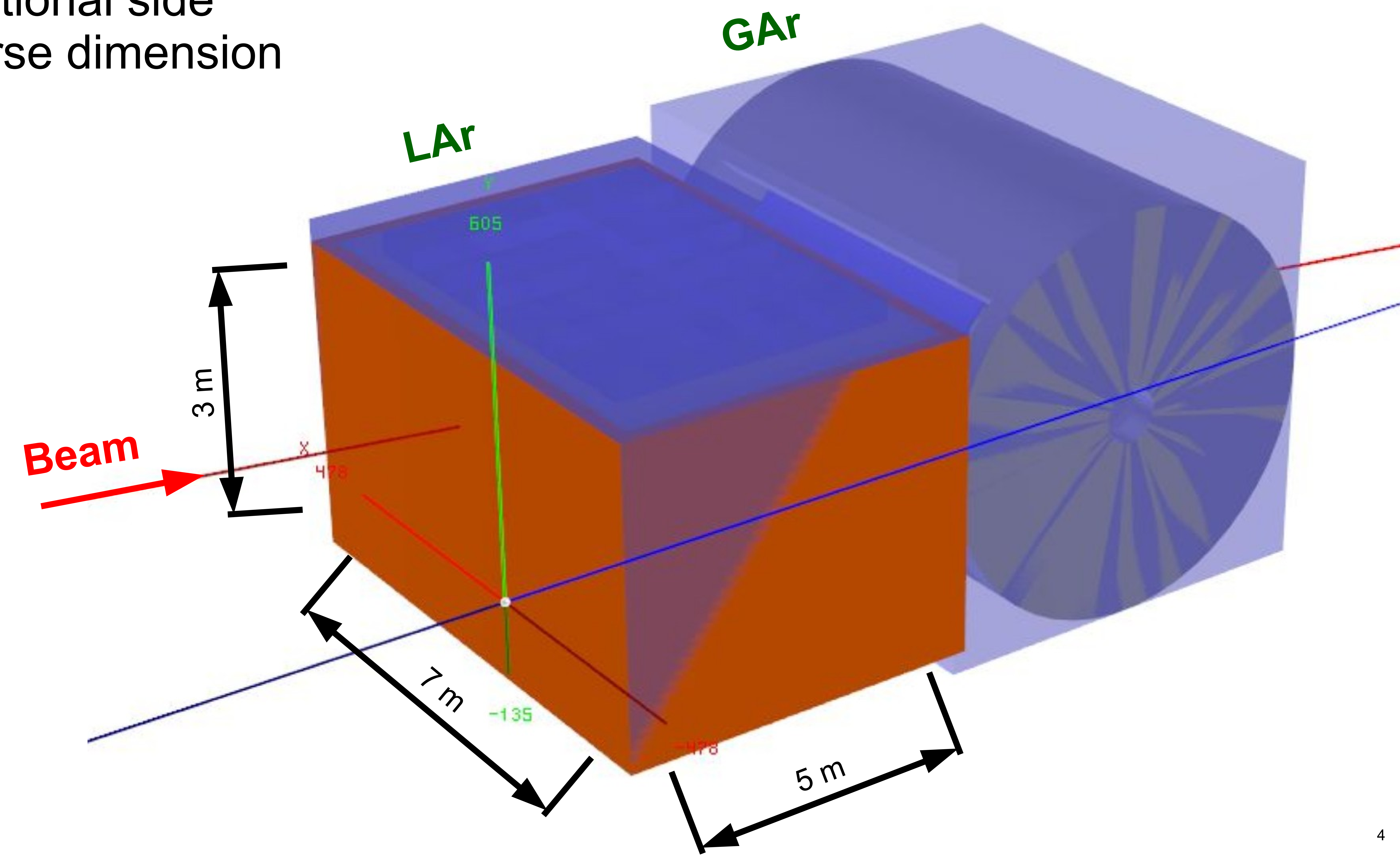
To mitigate the need for additional side muon spectrometer, transverse dimension increased to **7 m**.

Active dimensions:

3 x 5 x 7 m^3

Active mass:

147 t (1.8 uBooNEs)



The Near Detector Environment

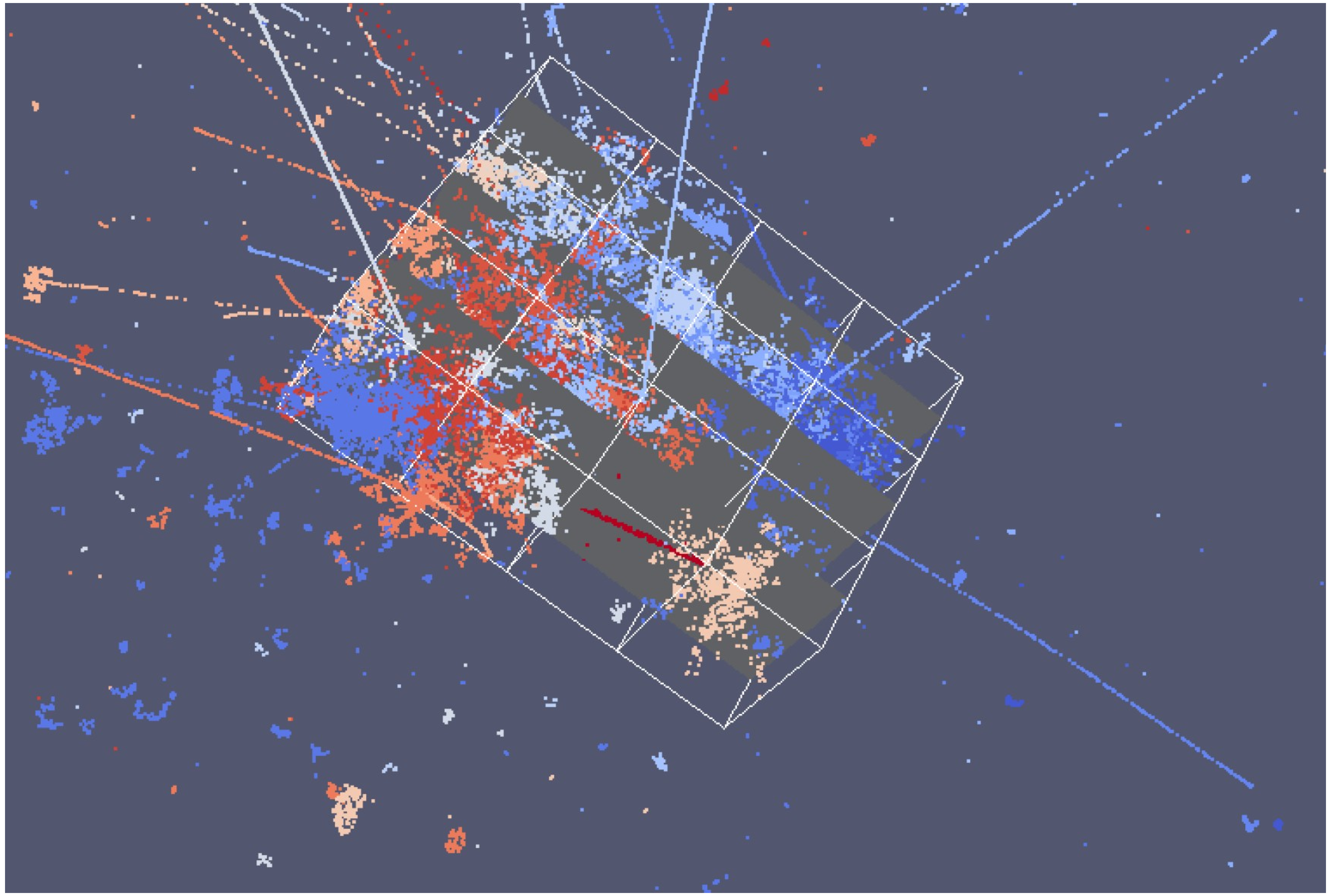
As Alan mentioned, the ND is a very high multiplicity environment.

0.1 events per tonne Ar per spill.

15 neutrino events per 10 μs spill.

37 M ν_μ CC events per year for a 25 t FV, (FHC at 1.07 MW).

How do you build a LArTPC to cope with this?



LBNF beam spill in ~200 t LAr volume, colouring by neutrino

ArgonCube

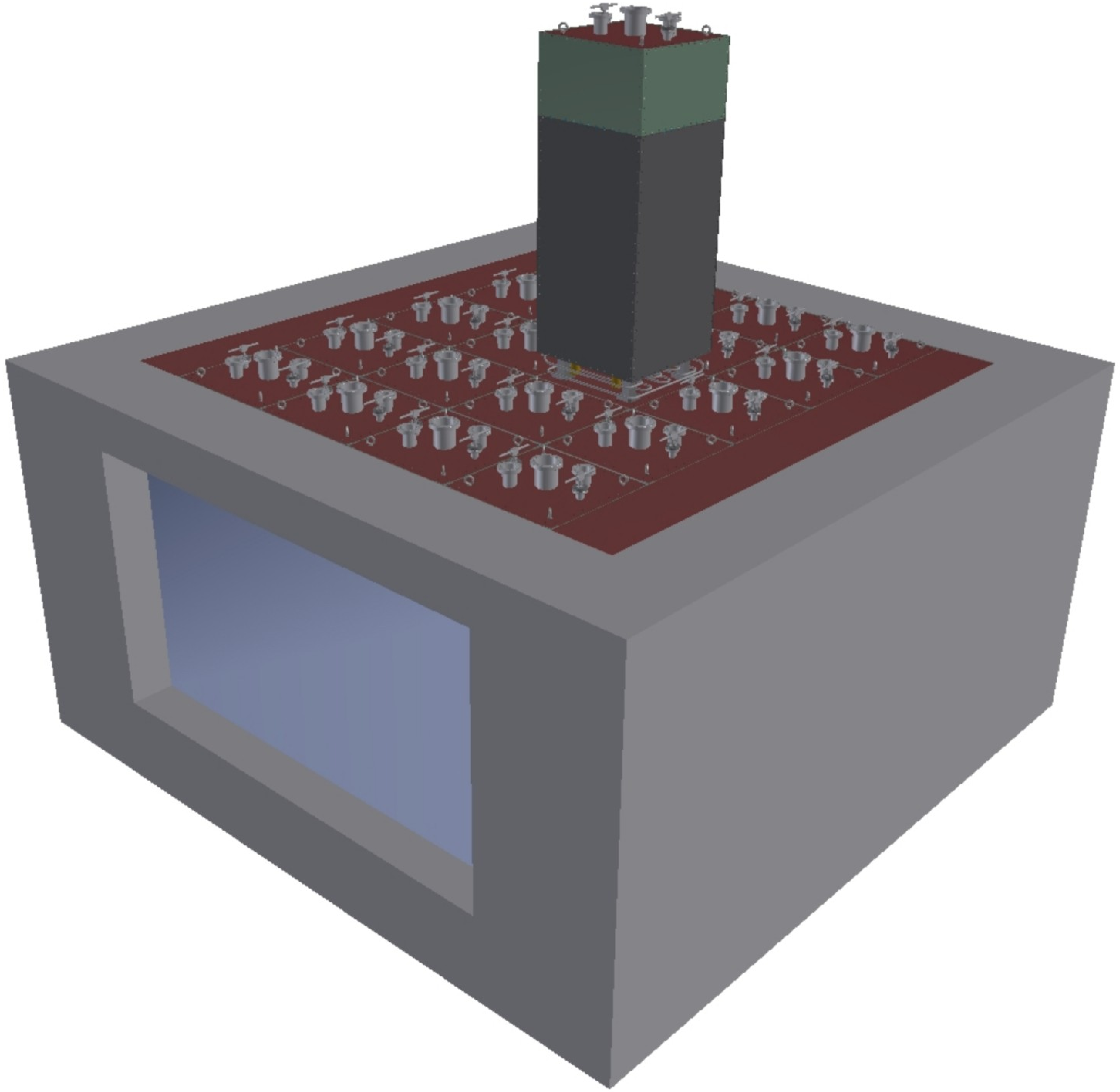
Segment the detector into a number of self-contained TPCs, sharing a common cryostat.

Shorter drift distances.
Reduced HV and purity requirements.

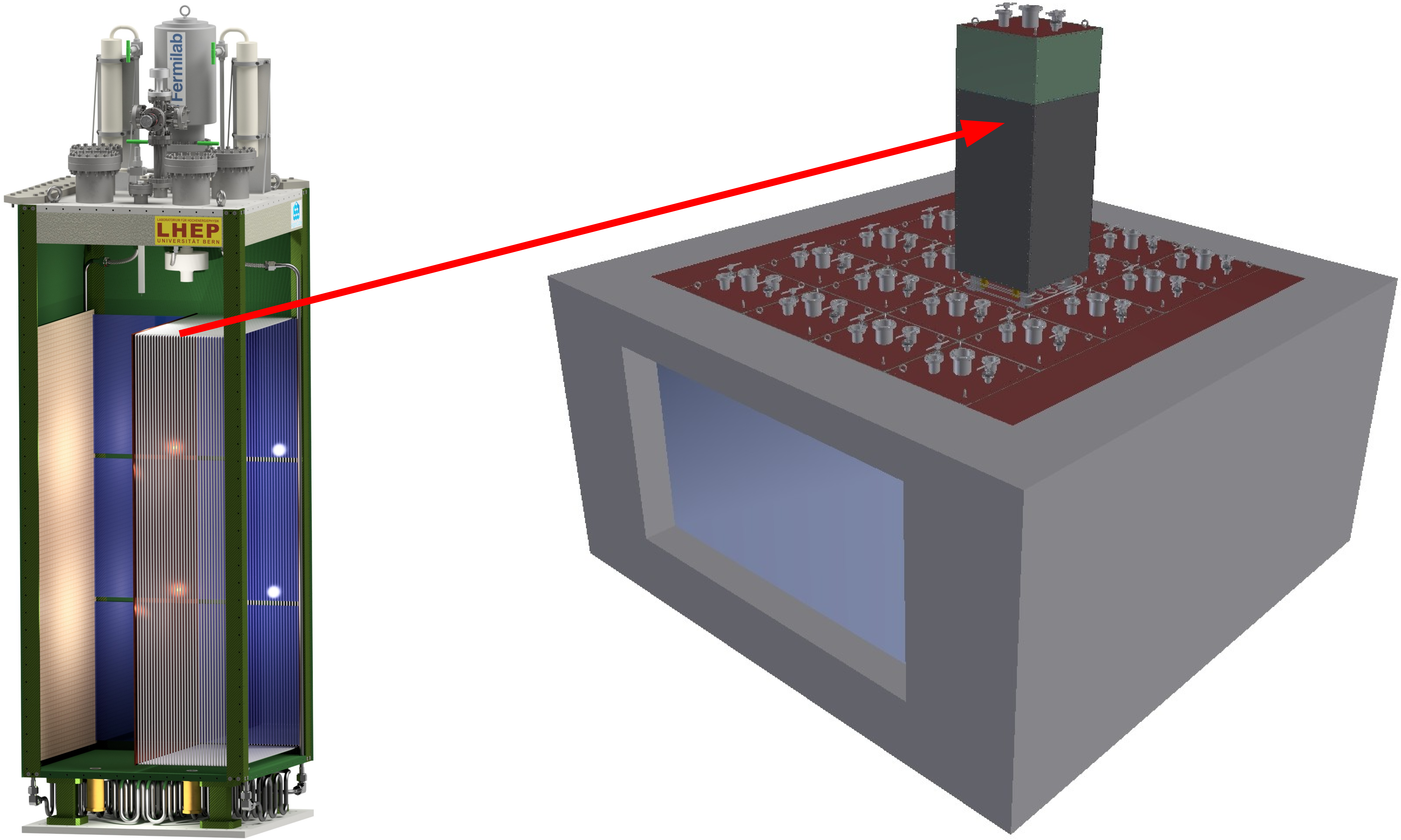
Ability to isolate effects of malfunctions in E-field or LAr purity.

Contained scintillation light.

Unambiguous charge readout.



Drawing of the baseline (5x4) ArgonCube ND component.

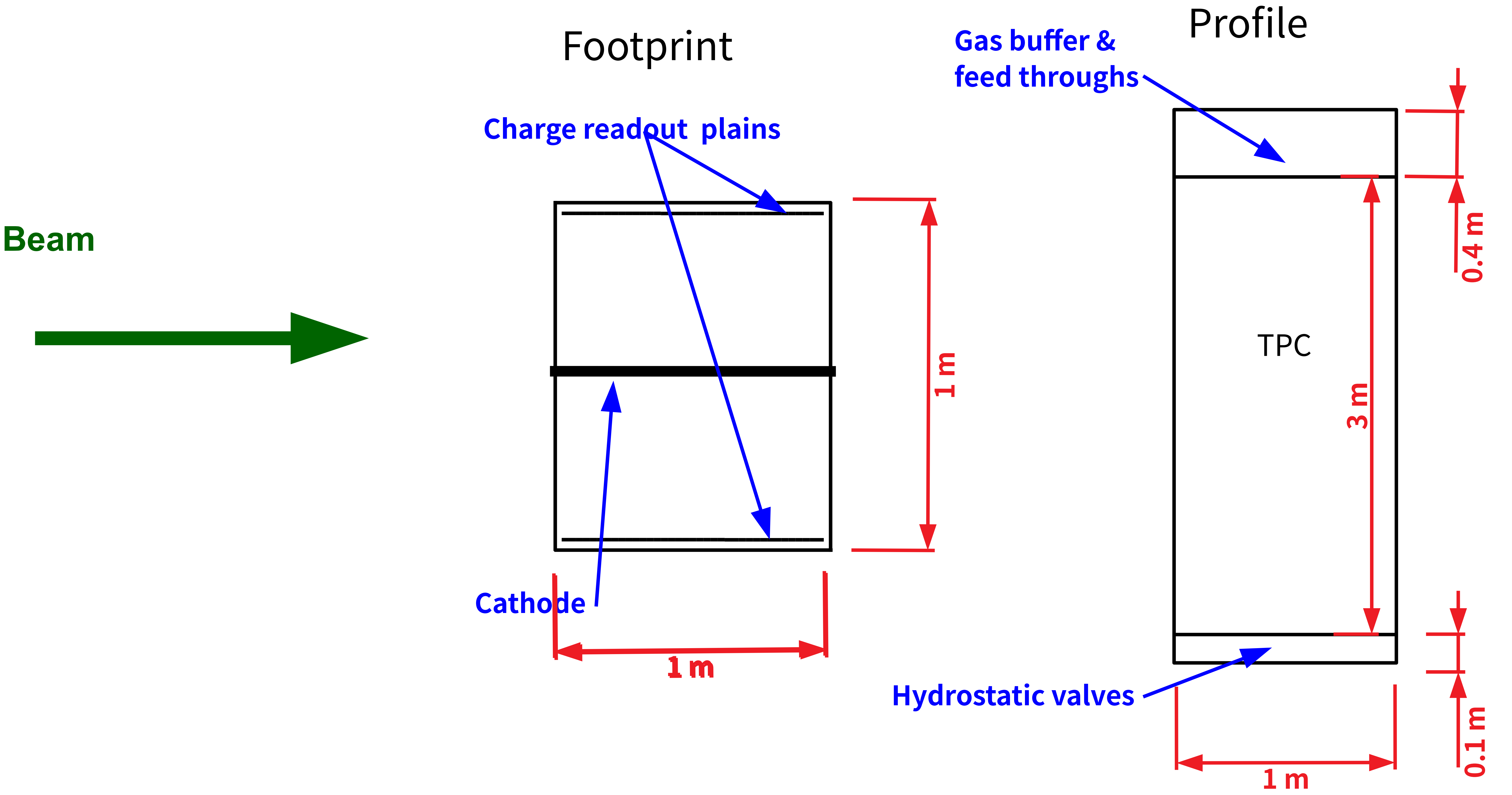


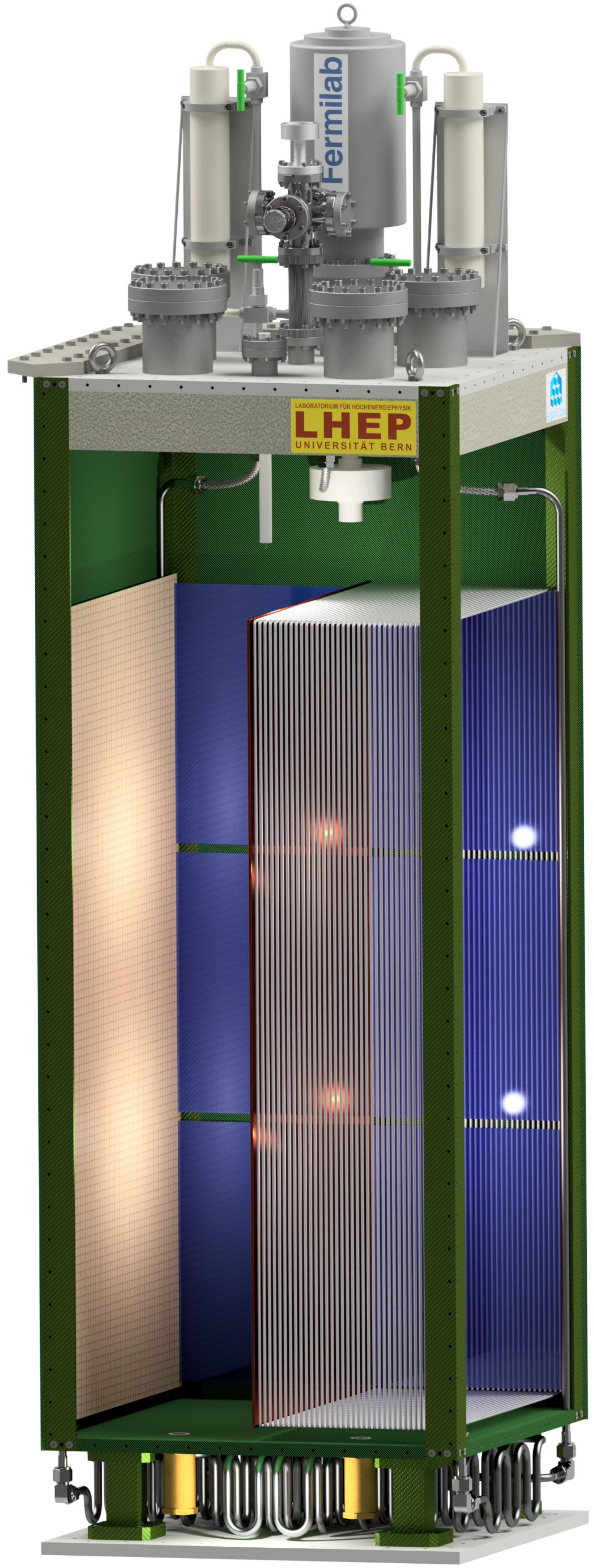
Cut-away illustration of an ArgonCube module, and an array of modules in a common cryostat (N.B. Modules will be sealed.)

ArgonCube in the ND

Each module: 1 m x 1 m x 3.5 m (50 cm drift, 50 kV)

Module dimensions set by Rayleigh scattering and diffusion.





ArgonCube Modules

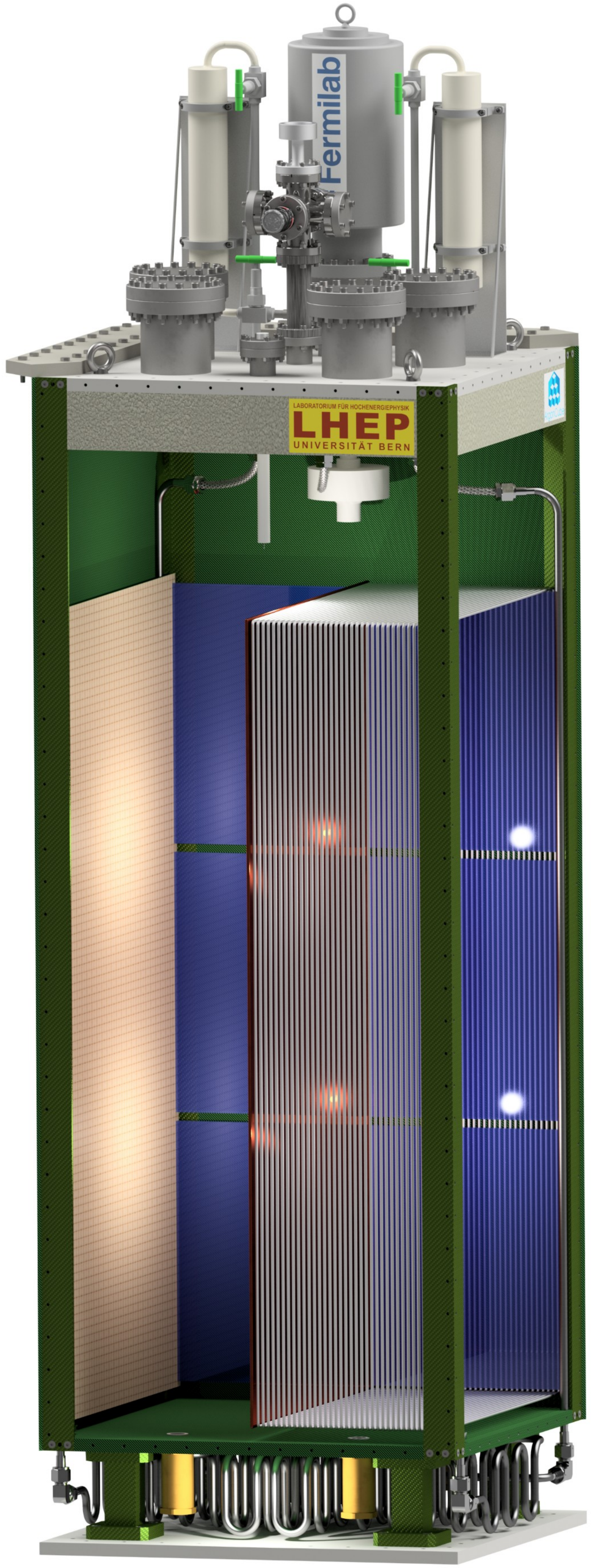
Dielectric G10 structure (200 kV/cm @ 1 cm)
Transparent to tracks:

	LAr	G10
Rad. Lenght (cm)	14.0	19.4
Had. Int. Length (cm)	83.7	53.1

Maximise active volume. Minimise dead material.

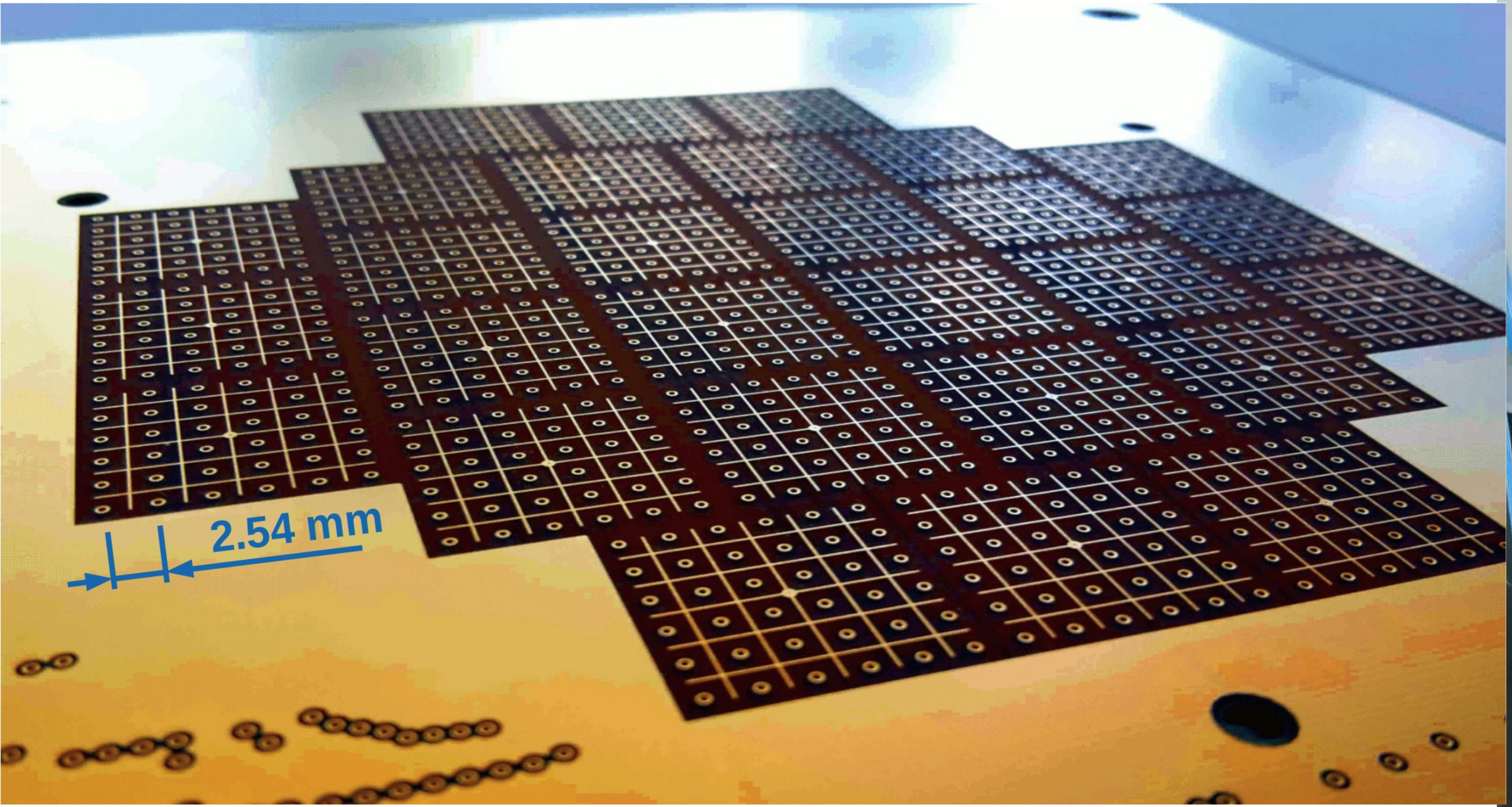
Charge readout:
Compact, mechanically robust, and unambiguous

Light readout:
Compact, dielectric, and large area coverage



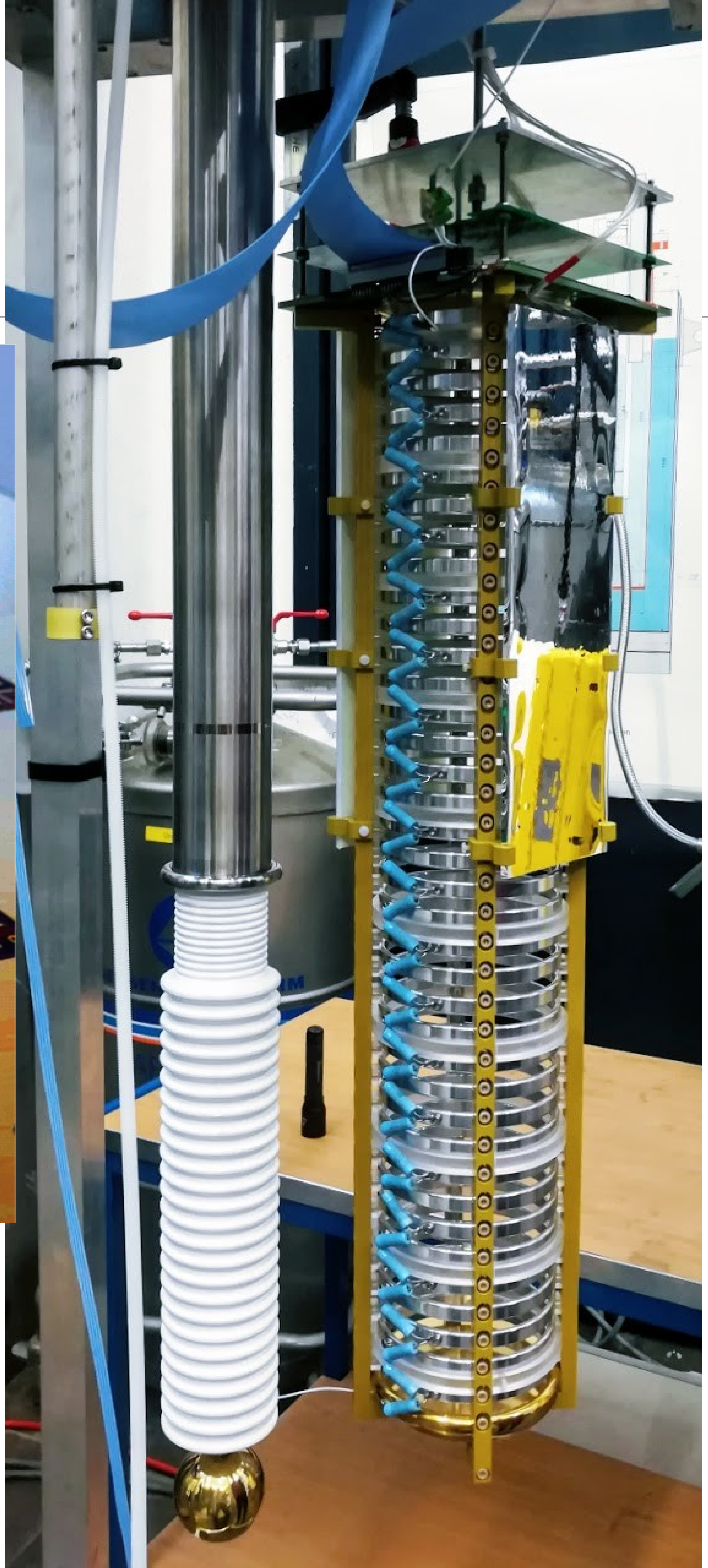
Cut-away illustration of an ArgonCube module

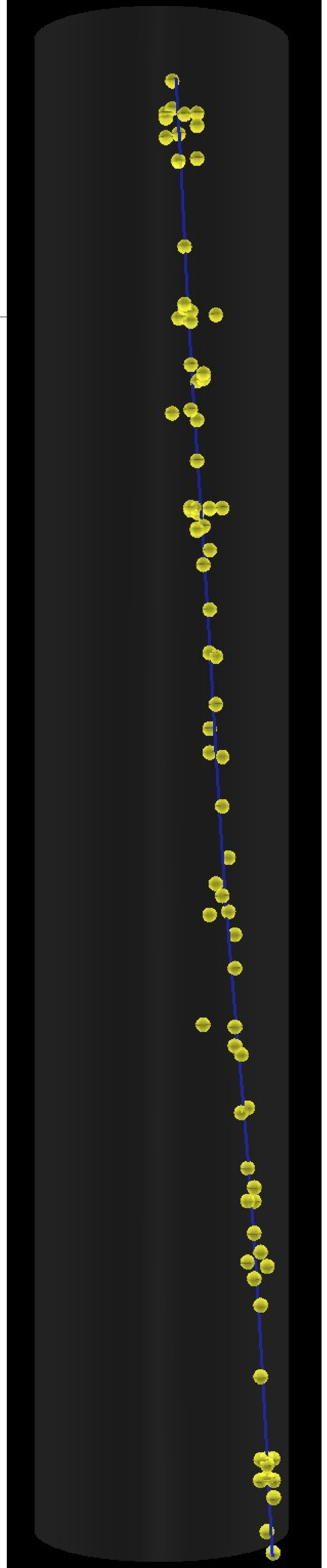
Pixel Demonstration TPC



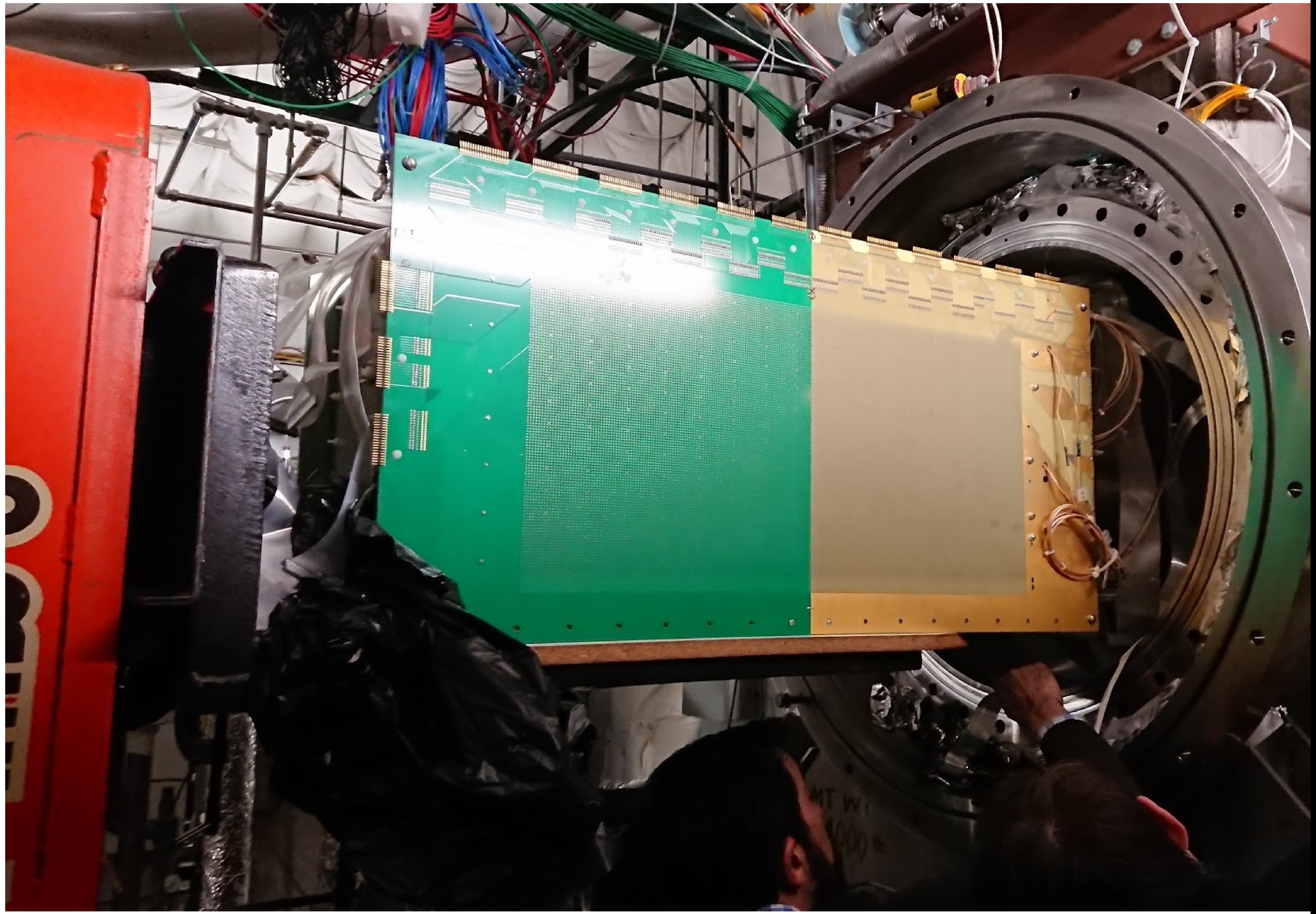
60 cm drift pixel demonstration TPC in Bern, first operated 2016 (arXiv:1801.08884).

N.B. Analogue multiplexing for LARASIC4*.

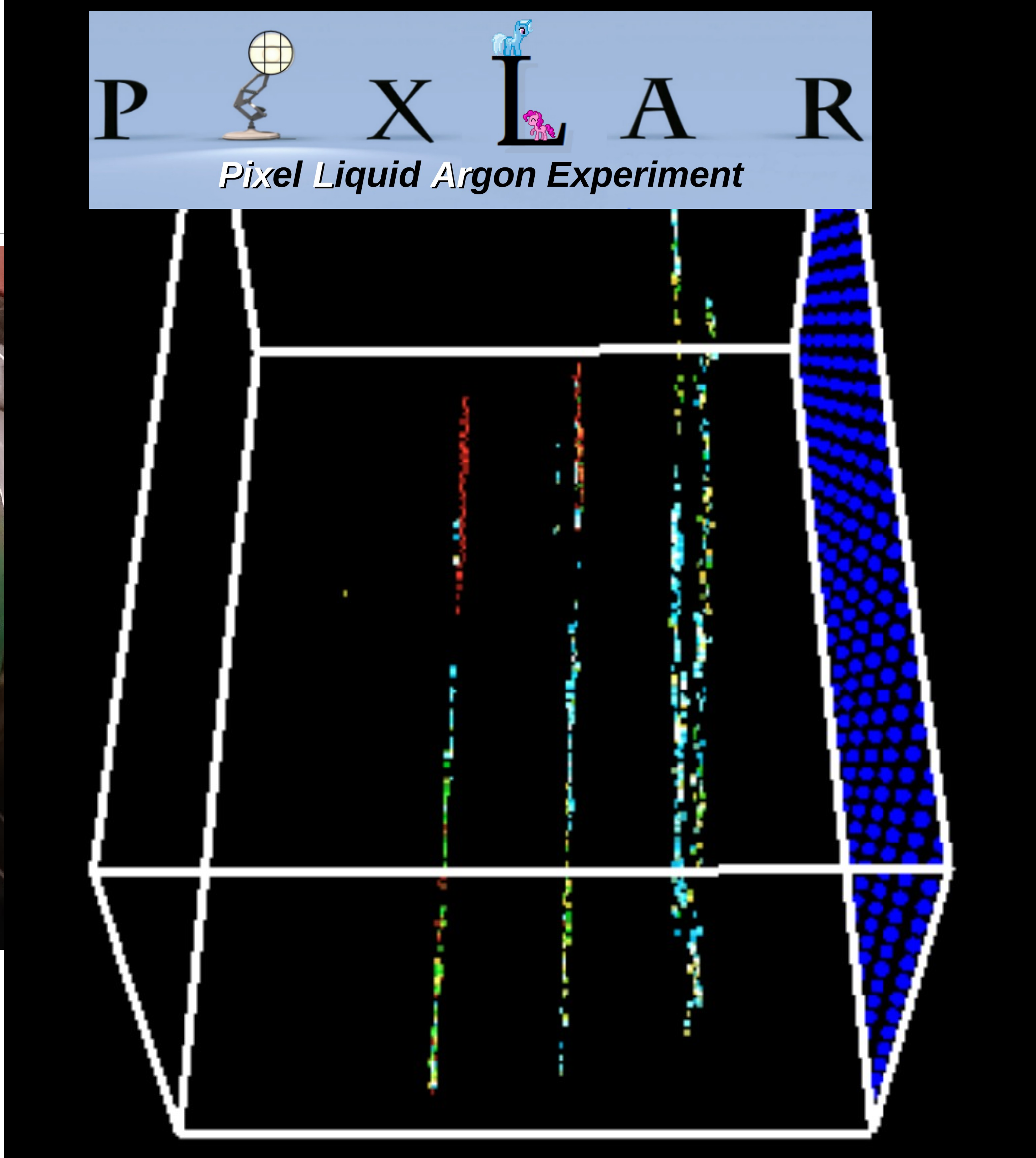




Pixels in a Test Beam



Pixel anode was fitted to LArIAT, operated winter 2017, analysis (led by UTA) is ongoing.



Pixel ASIC Development - LArPix

LBNL (Dan Dwyer) has lead the development of LArPixV1 ASIC (arXiv:1808.02969).

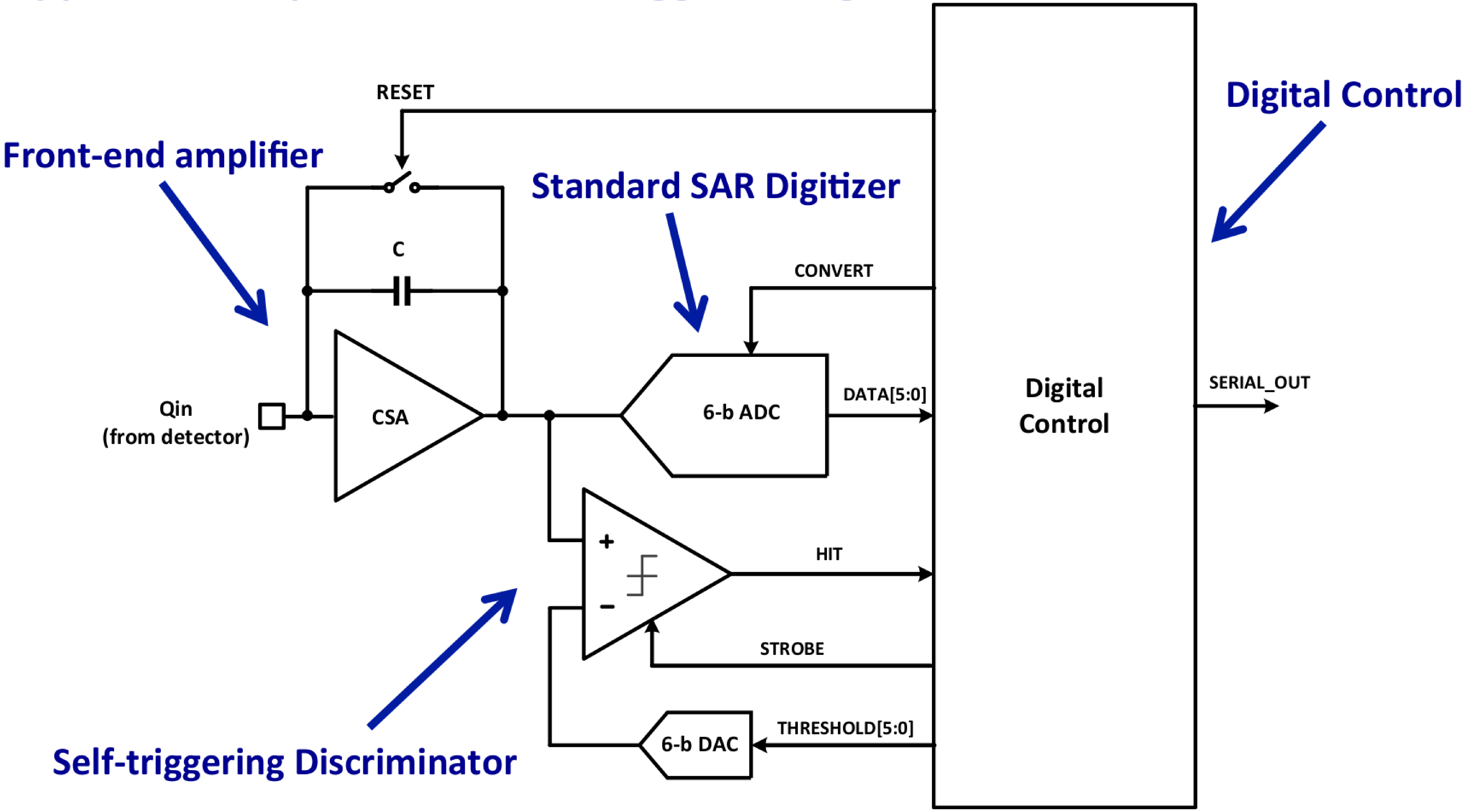
Cold amplification and digitisation demonstrated with.

Self-triggering & pulsed reset is not zero suppression! But, it does make for very low data rates

60 cm TPC, 512 pixels, ~0.3 Hz
~3 kB/s

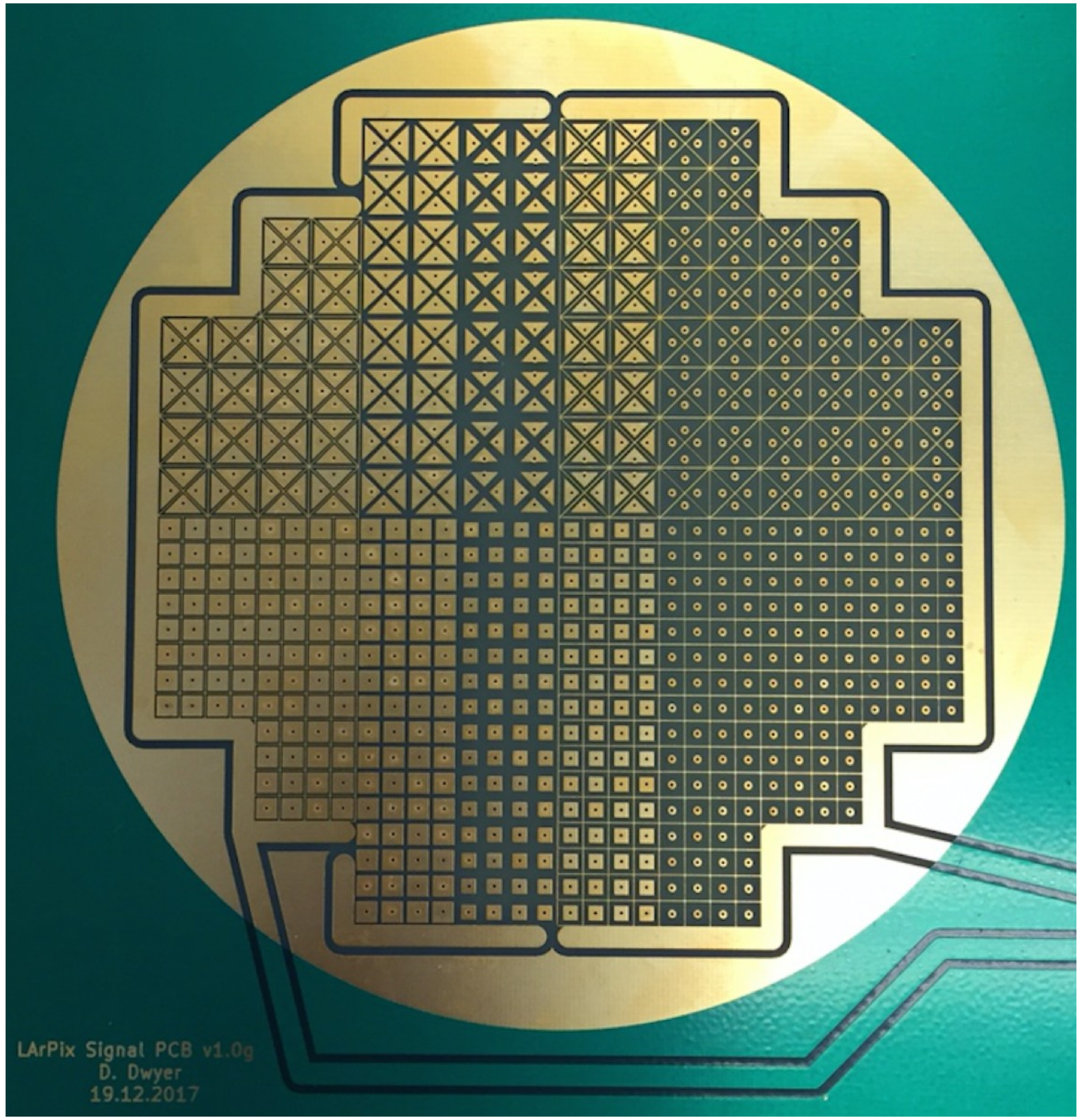
DUNE ND, 8M pixels, ~0.01 Hz
~2 MB/s

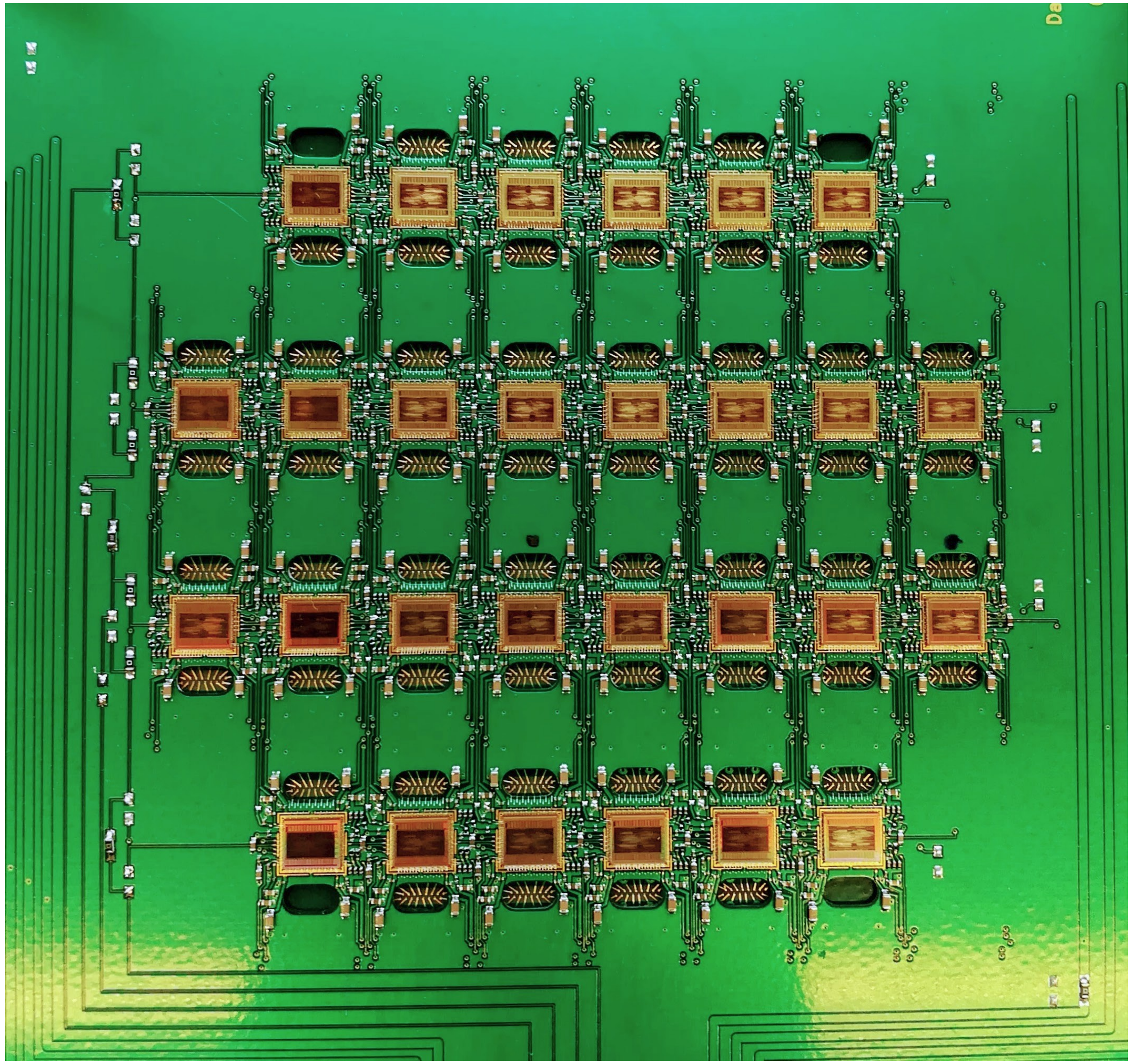
Approach: Amplifier with Self-triggered Digitization and Readout



Achieve low power: avoid digitization and readout of mostly quiescent data.

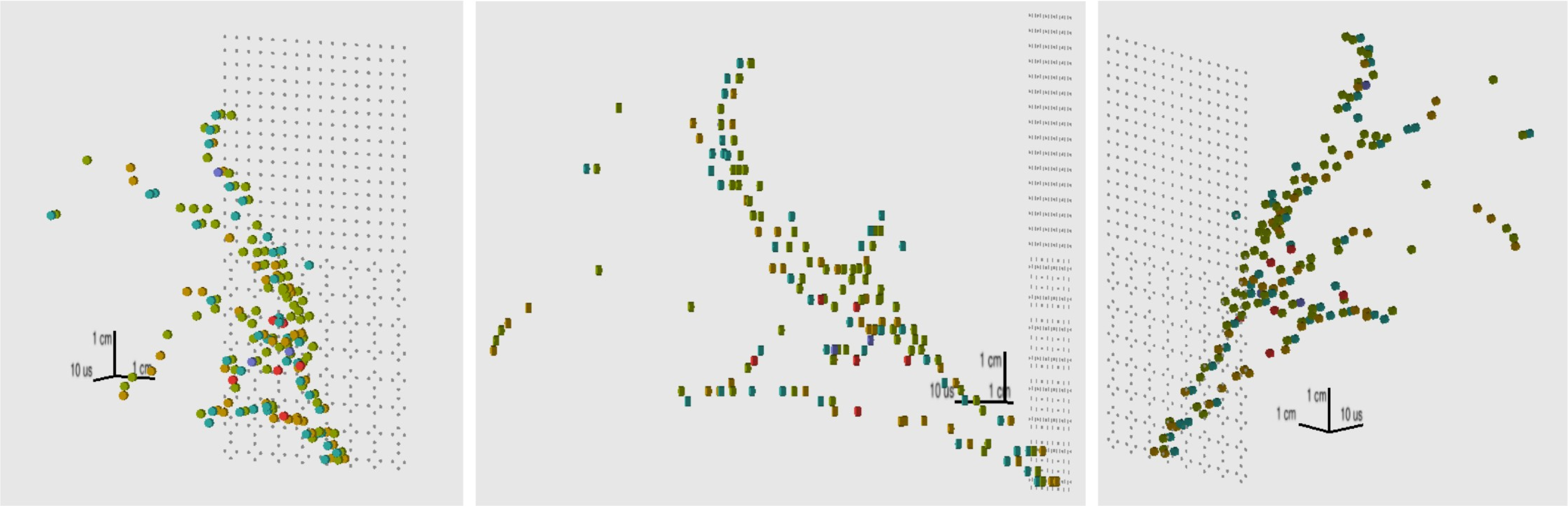
LArPix





832 pixel anode PCB (pixel geometry optimisation), LArPixV1 ASIC mounted on reverse of pixel anode.

LArPix – True 3D



LArPix provides direct access to unambiguous 3D space points; drastically simplifying event reconstruction!
See https://goo.gl/AdVC9s for interactive events.

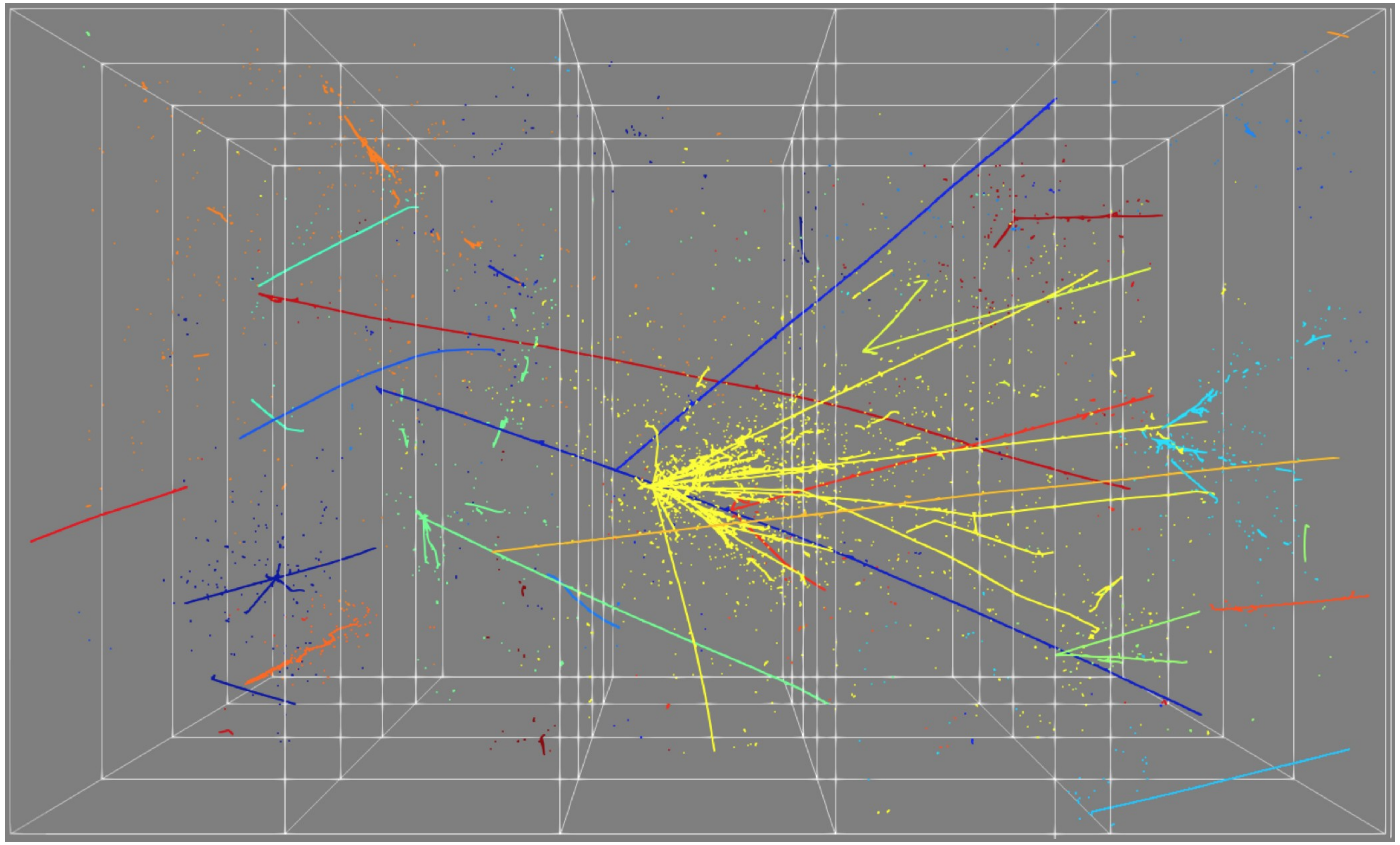
Light Readout - ArCLight

Unambiguous charge R/O will simplify reconstruction, but it is still timing limited:

Drift window = 250 μs.
Spill =10 μs.

It is not trivial associating isolated/detached deposits to correct vertex – fast neutrons.

Contained scintillation can help, light R/O with ~ns resolution needed.



1 MW 3 horn optimised spill, FHC, including rock. 4x5 geometry. Colouring by nu.

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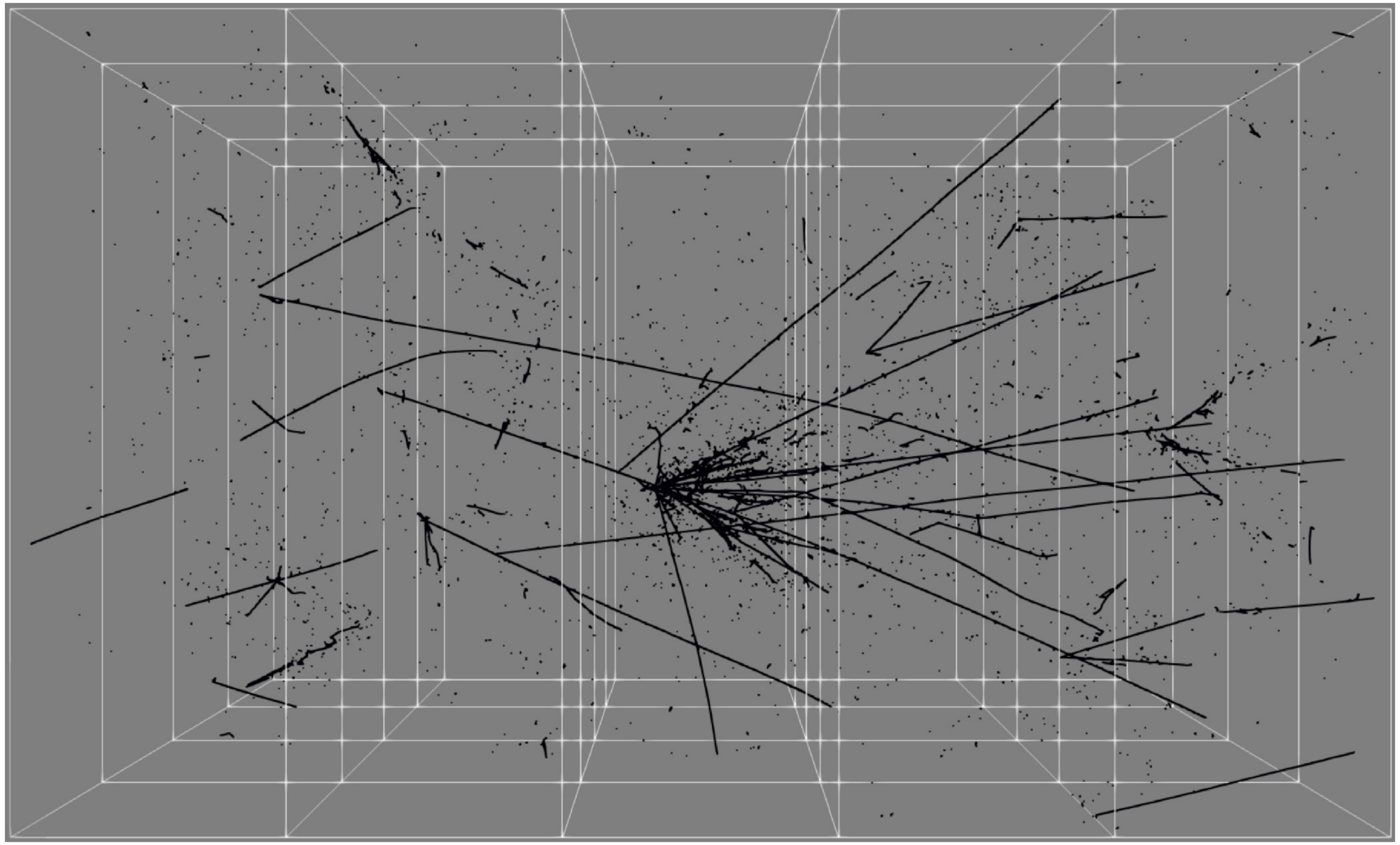
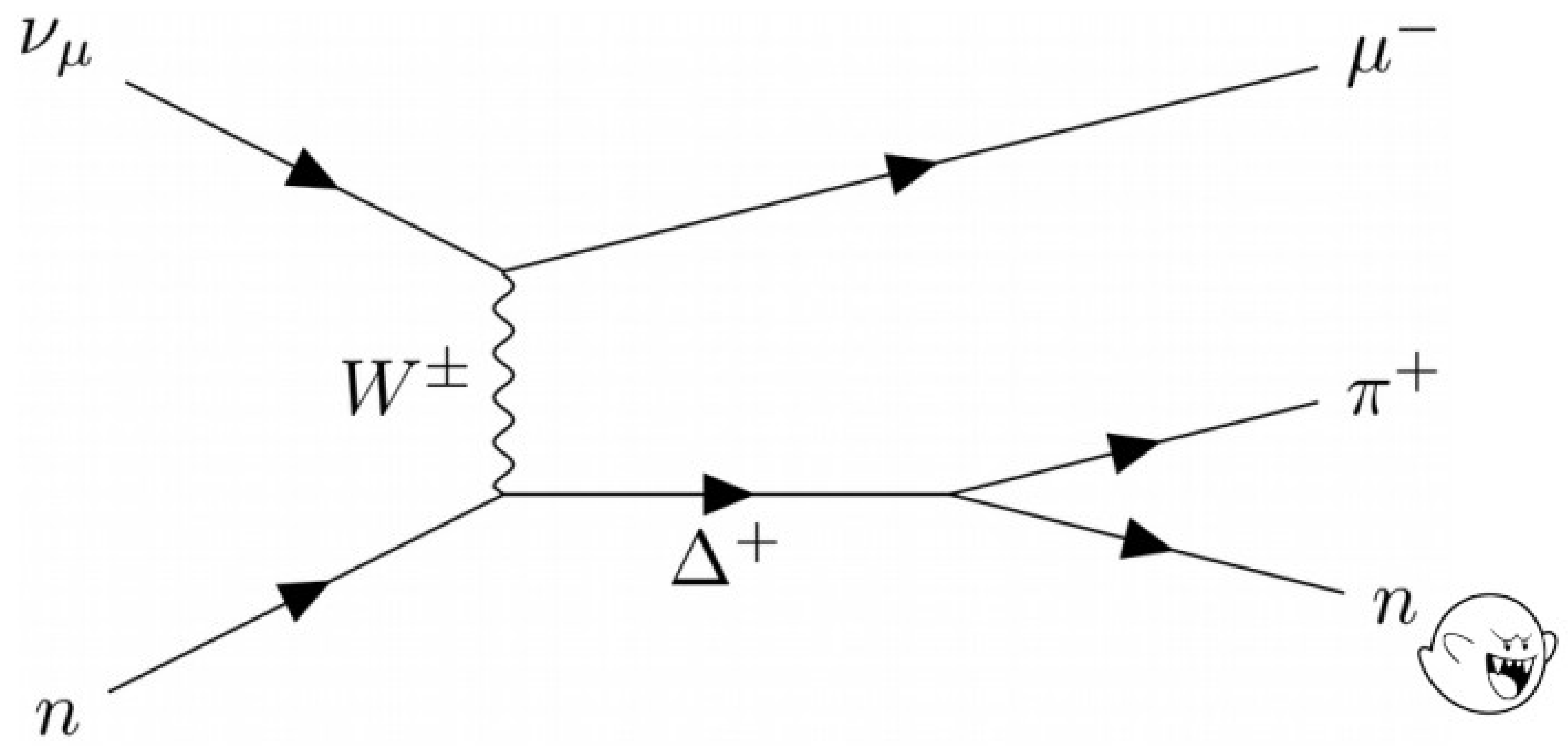


1 MW 3 horn optimised spill, FHC, including rock. 4x5 geometry. Colouring by charge R/O.

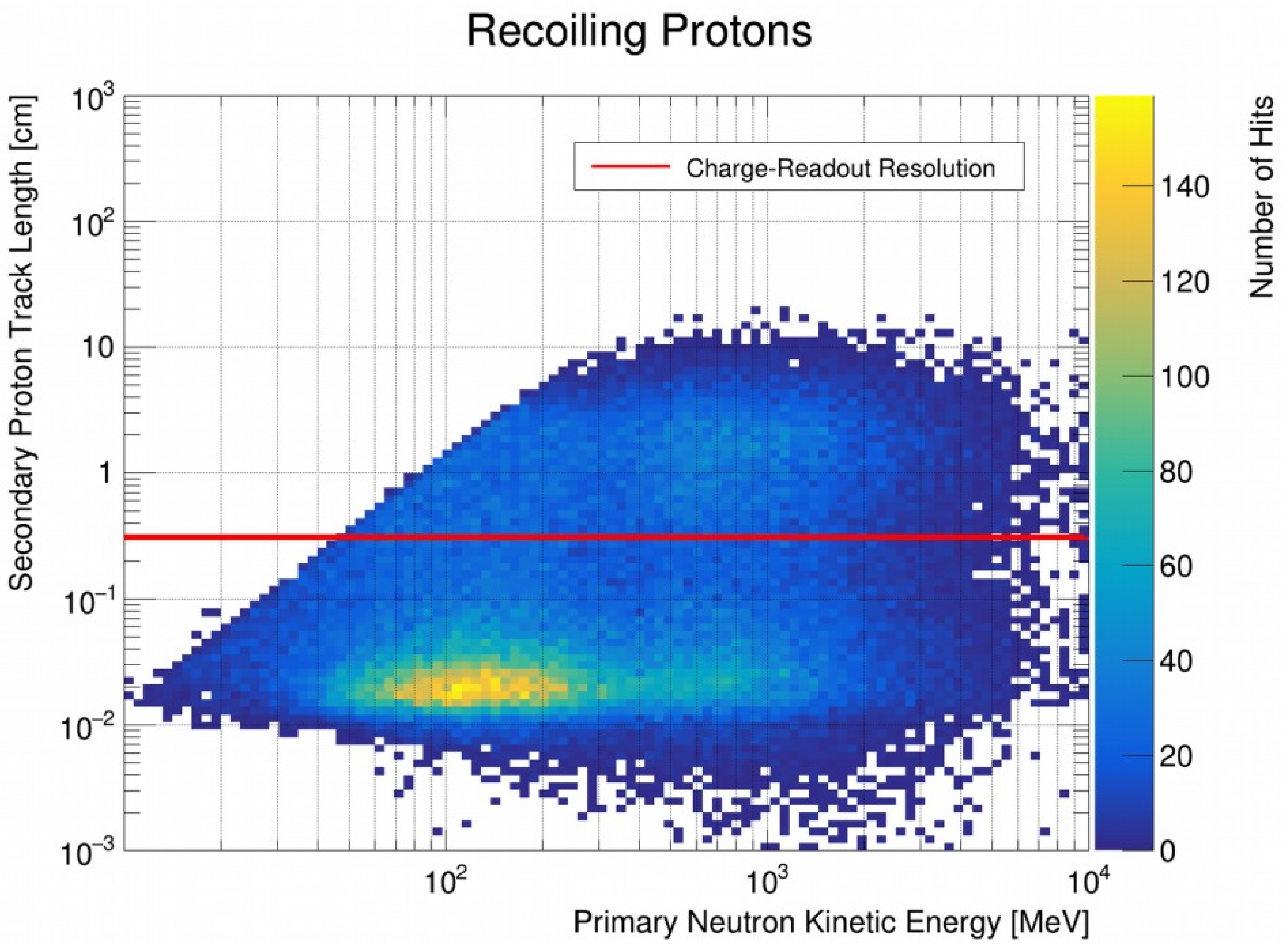
Why Attempt Tagging Neutrons in LAr?

Studies from Patrick Koller.



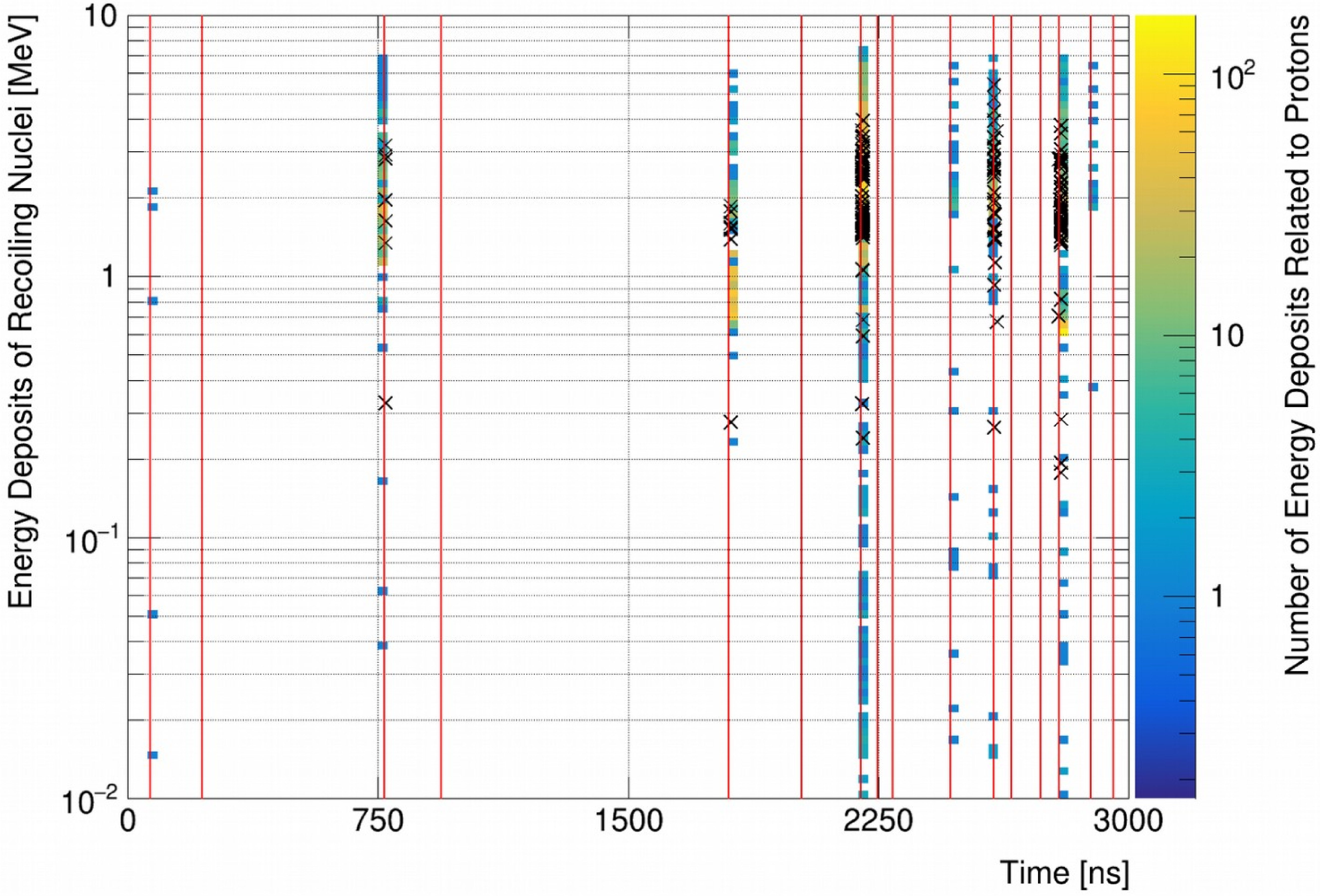
$$E_{\nu,reco} = \underbrace{E_\mu}_{leptonic} + \underbrace{\sum_{i=p,\pi^\pm} E_i}_{hadronic} + \underbrace{\sum_{i=\pi^0,e,\gamma} E_i}_{EM-showers} + \cancel{\underbrace{\sum E_n}_{neutrons}}$$

Hadronic showers can also fluctuate to neutrons

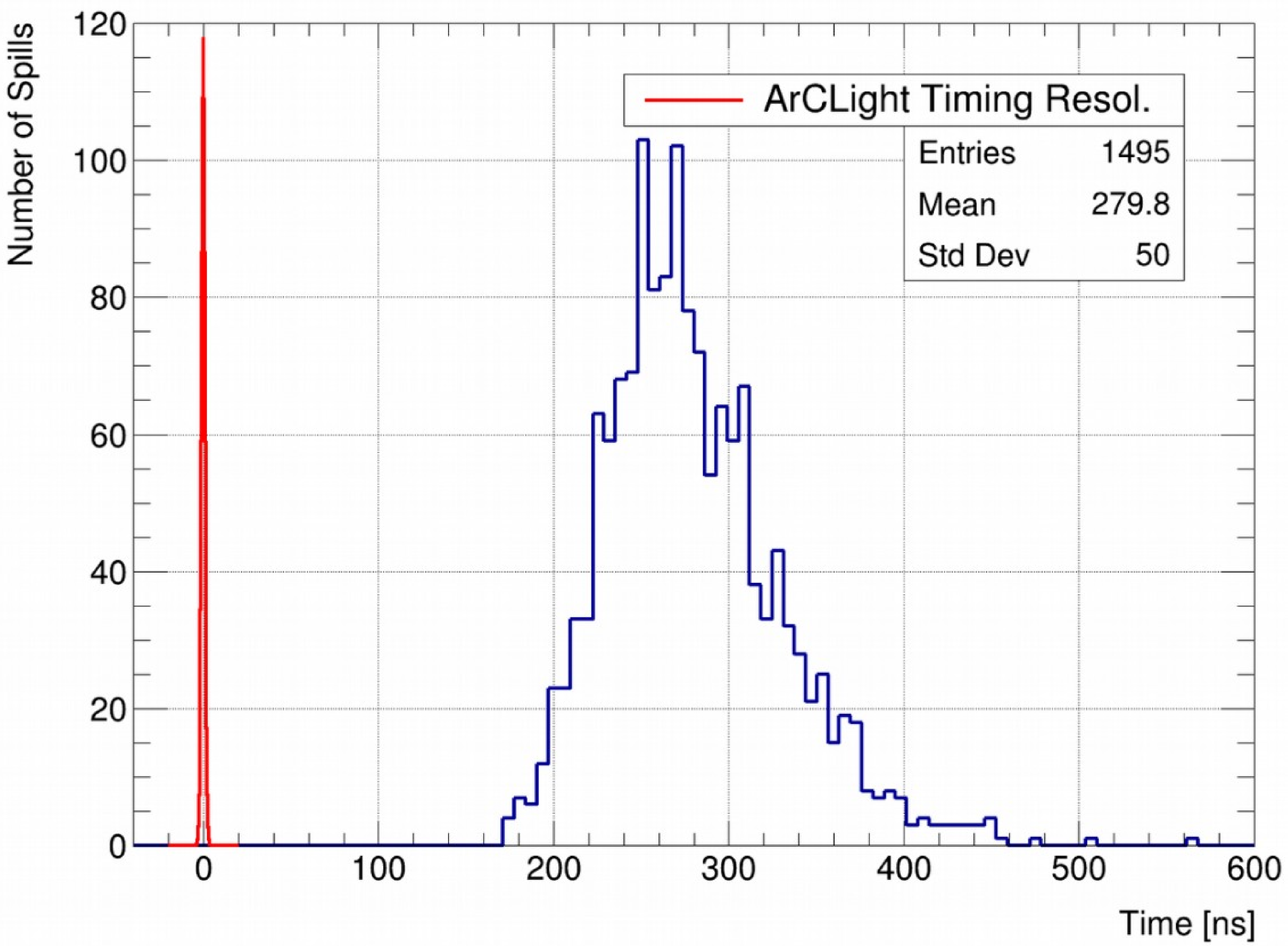


Tracks from recoiling protons at neutron energies > 50 MeV (~30% of all recoiling protons)

Neutrino Vertex Temporal Separation



1/3 of a 1 MW 3 horn optimised, FHC spill
Temporal separation of neutrino events (red), recoiling protons(coloured), and nuclear recoil (X)



The mean temporal separation of vertices in a spill

Use prompt light from protons and vertex to associate tagged fast neutrons with correct ν-interactions.

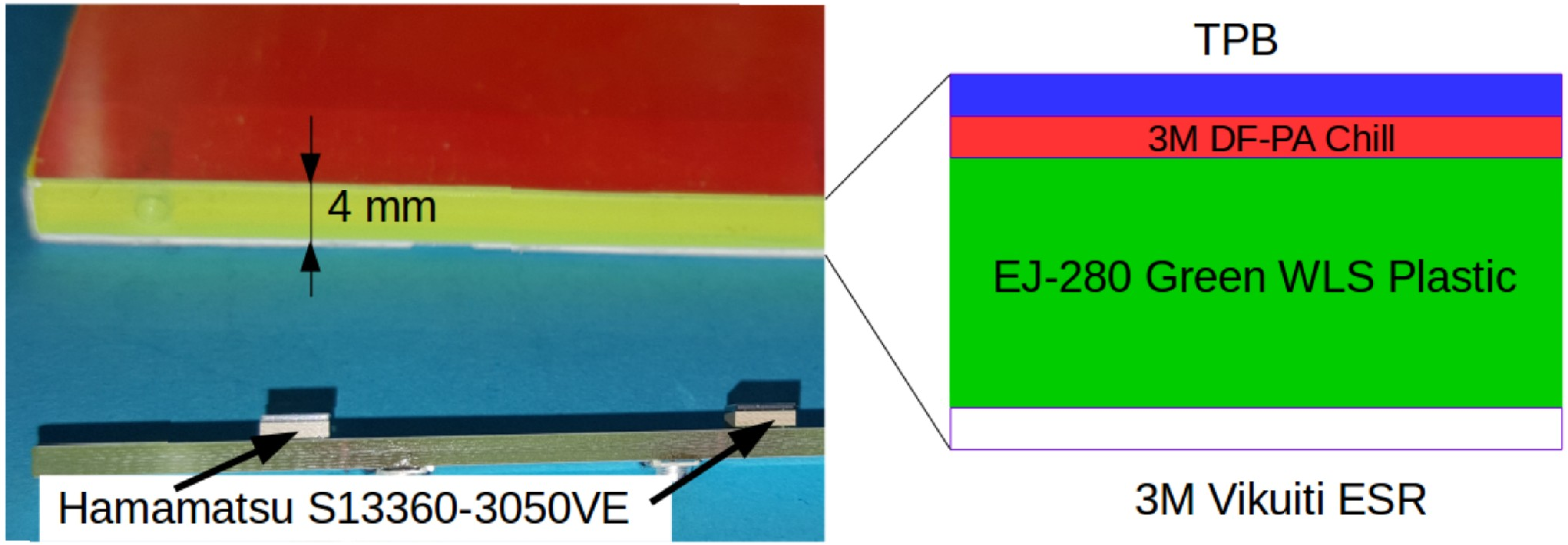
Light Readout - ArCLight

A compact dielectric light R/O: ArCLight(arXiv:1711.11409).

The dielectric bulk can be deployed within the TPC, covering a large area.

Successfully operation in test beam at FNAL. Further characterisation in progress.

Spatial resolution requirements of fast-neutron tagging will be used to optimise dimensions.



ArCLight cross-section

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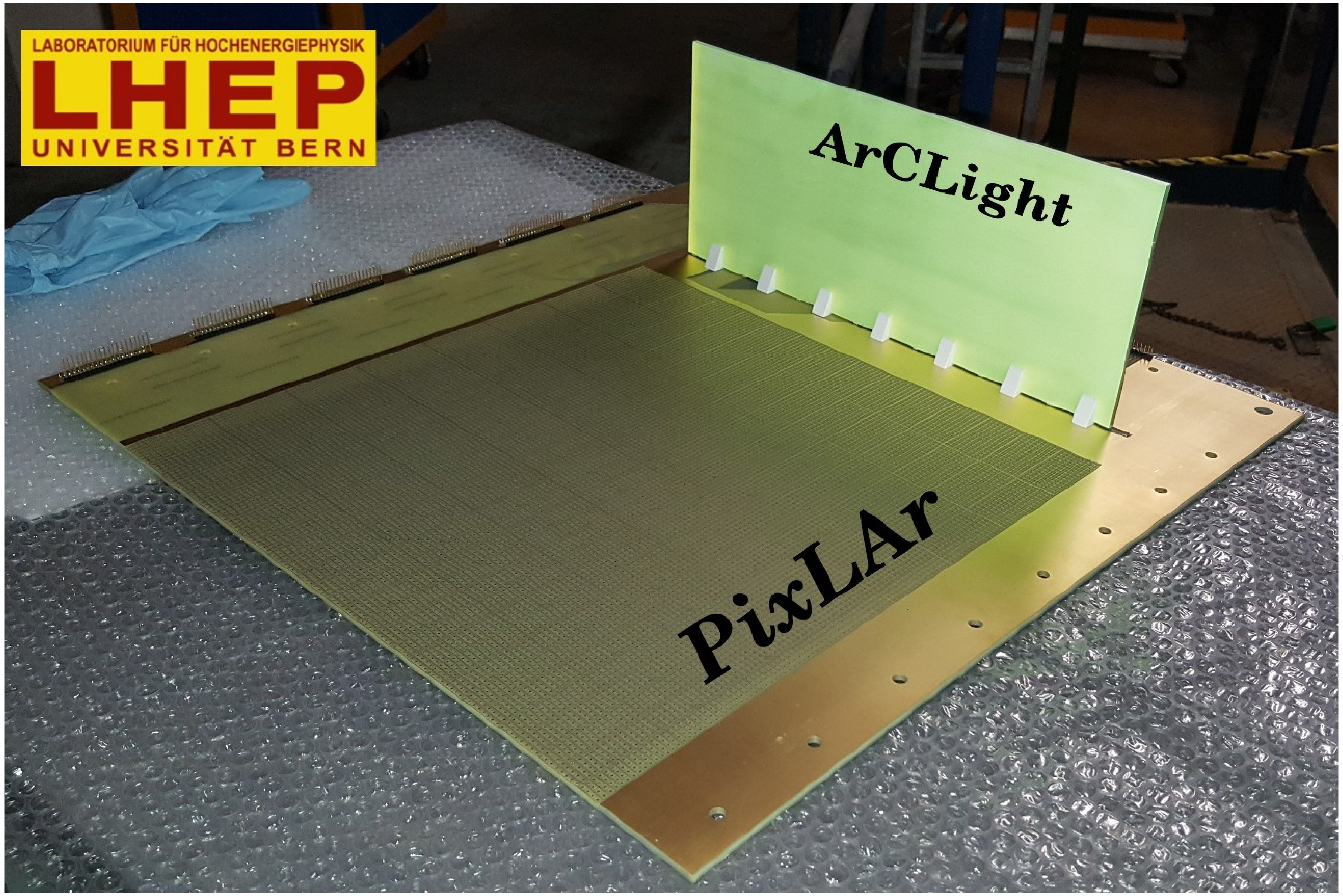


ArCLight mounted on one half of the PixLAr pixel plane

Field Cage → Field Shell

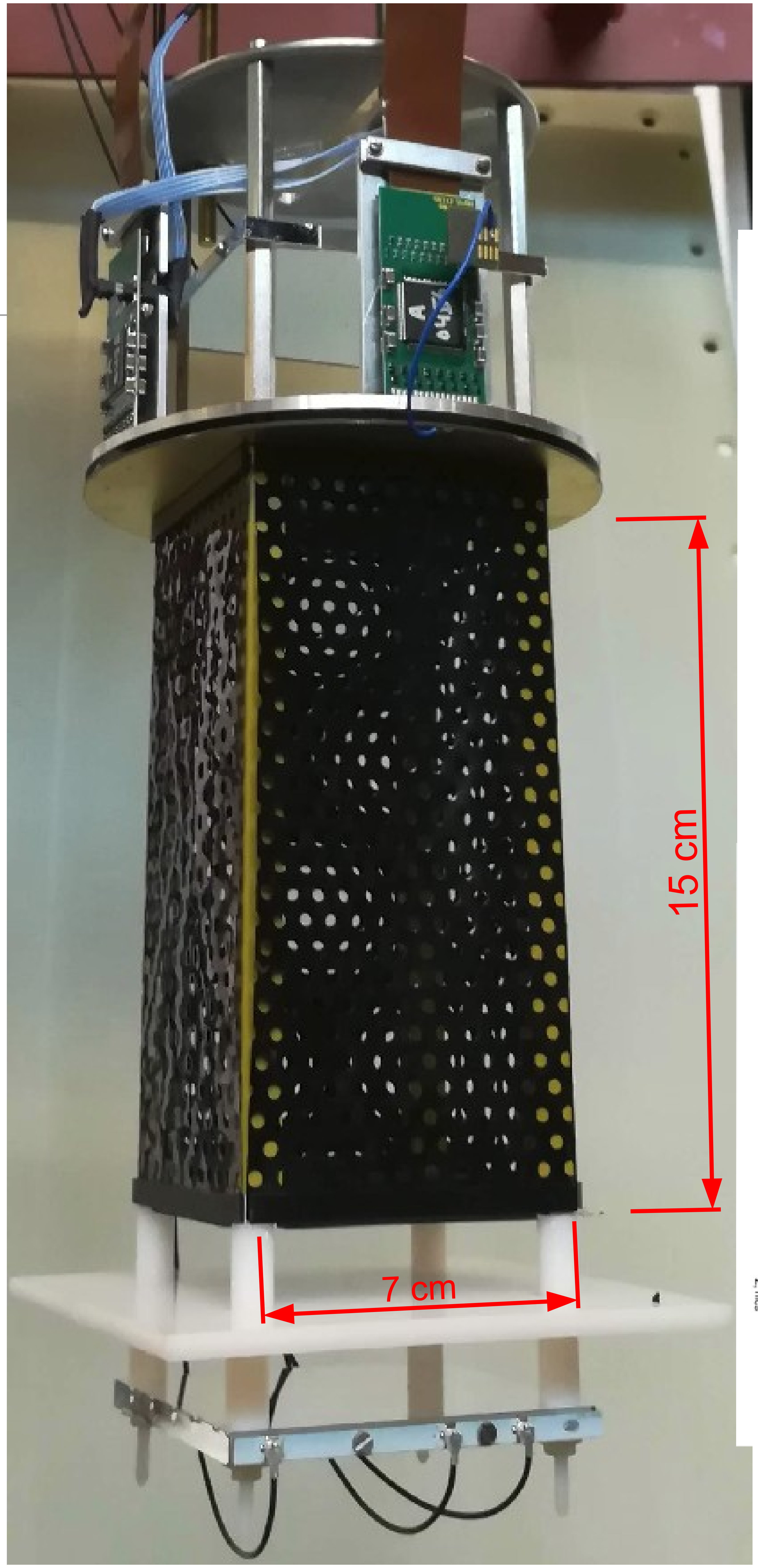
Continuous resistive plane formed of 50 μm carbon-loaded Kapton (selected by Ting Miao of FNAL).

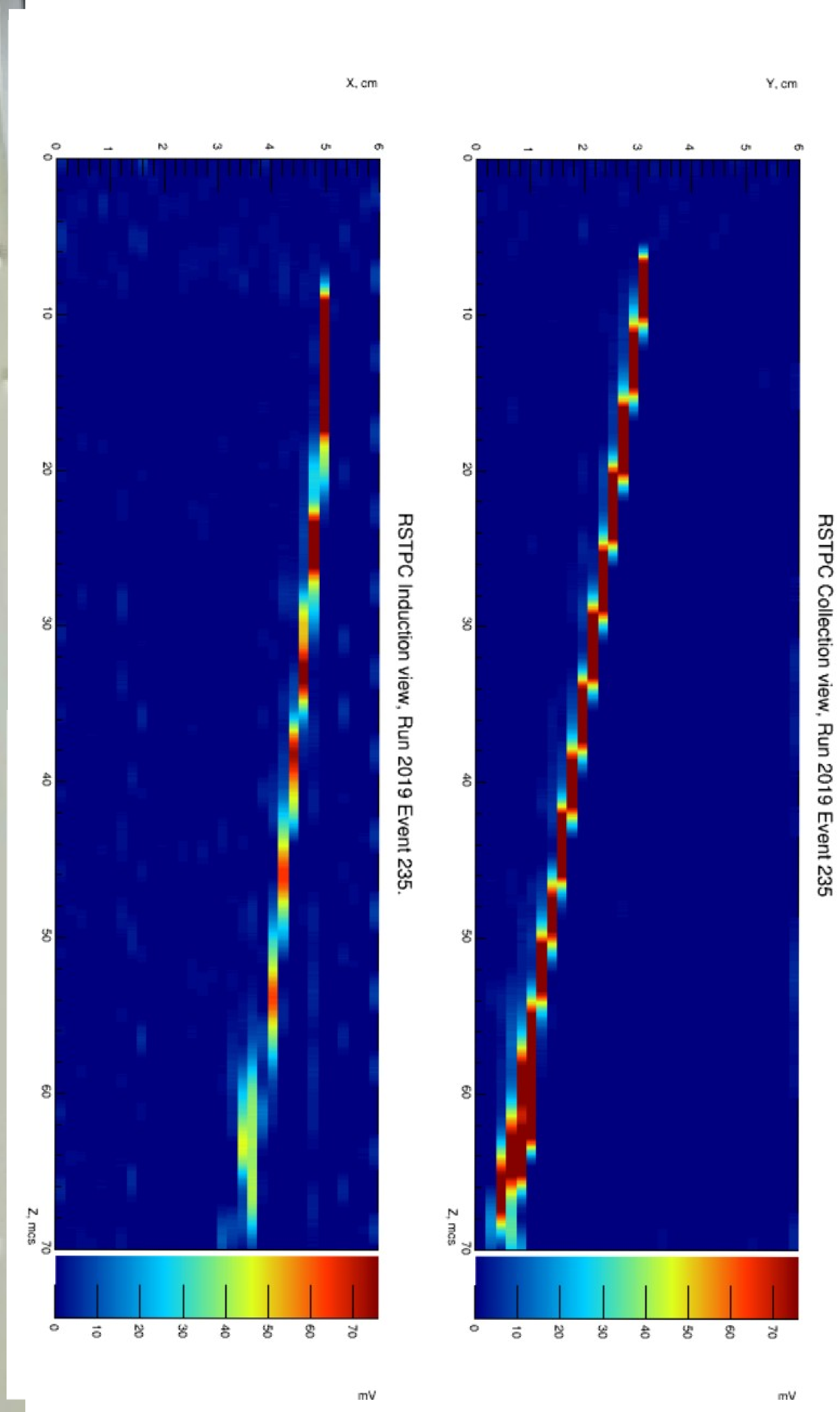
15 cm drift TPC.
E-field range 0 kV/cm → 1.5 kV/cm.

Triggering on crossing muons.

Straight tracks observed across a range of E-fields.

Field uniformity analysis pending.





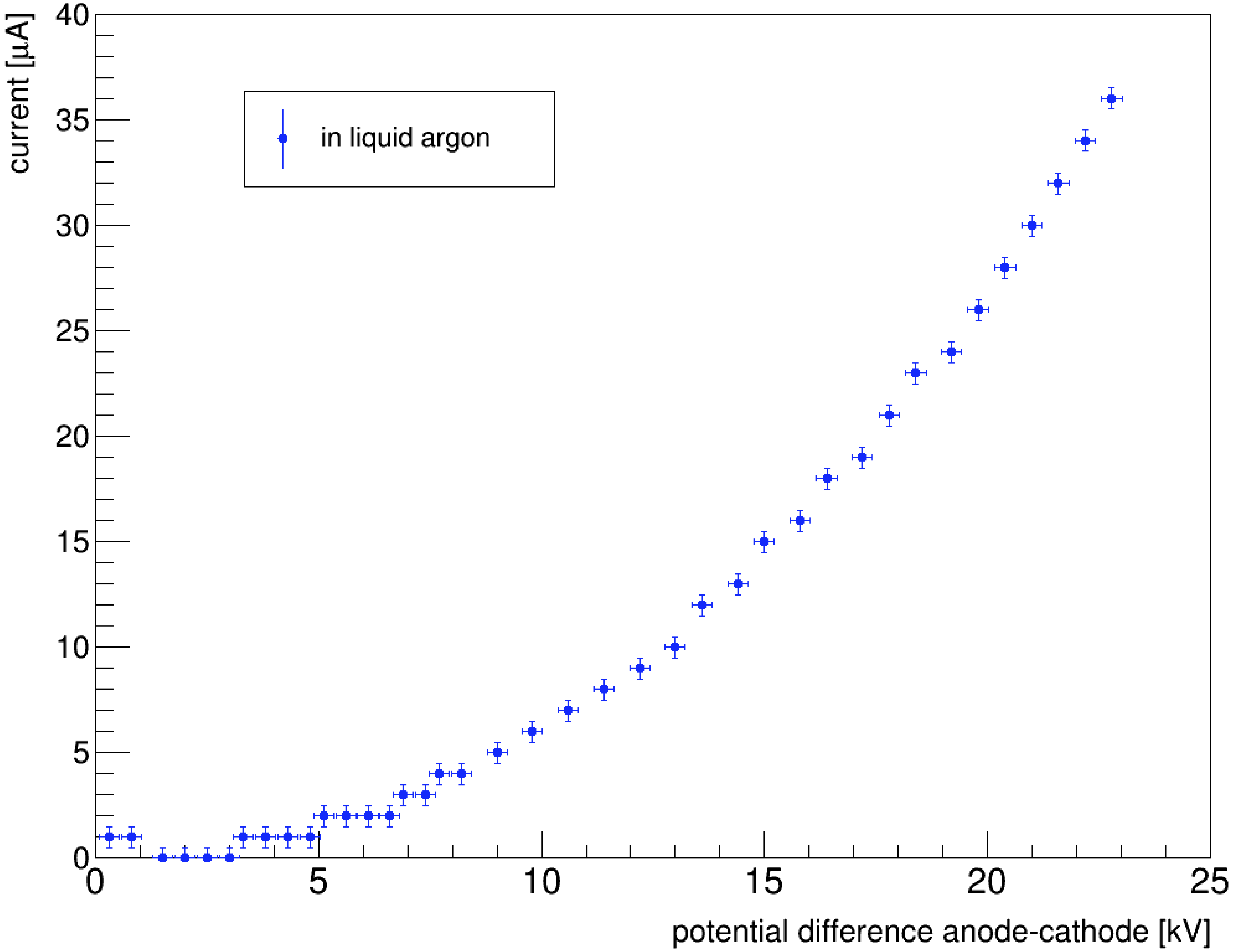
Resistive Shell TPC Results

Non-linear I-V relationship observed at HV supply.

Resistivity remained in desired range O(1) GΩ/sq.

Results are promising, but must be tested for larger sample.

2 GΩ/sq @ 1 kV/cm.



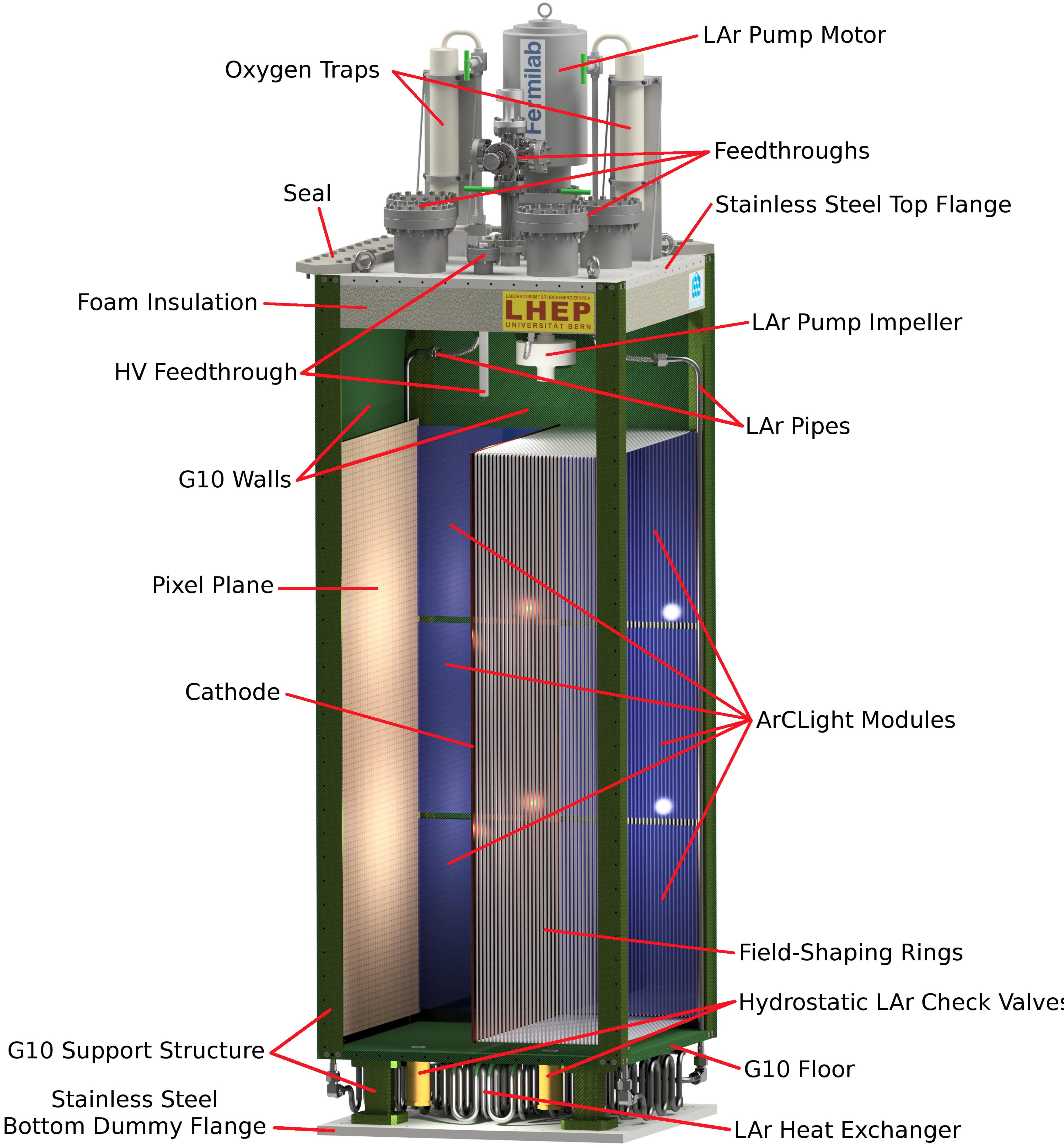
ArgonCube Modules

The feasibility of all technologies has been demonstrated. The next step is detector construction.

The first ArgonCube module will be deployed in the 2x2 Demonstrator in Bern this winter, testing module cryogenics.

The 2x2 will be populated with 4 fully instrumented modules by winter 2019.

Following a cosmic run, the 2x2 will be moved to FNAL in early 2020. Into the NuMI beam, in the MINOS ND hall, to from part of **ProtoDUNE-ND**.



2x2 Demonstrator module.
N.B. ND modules will not have individual pumps & filters

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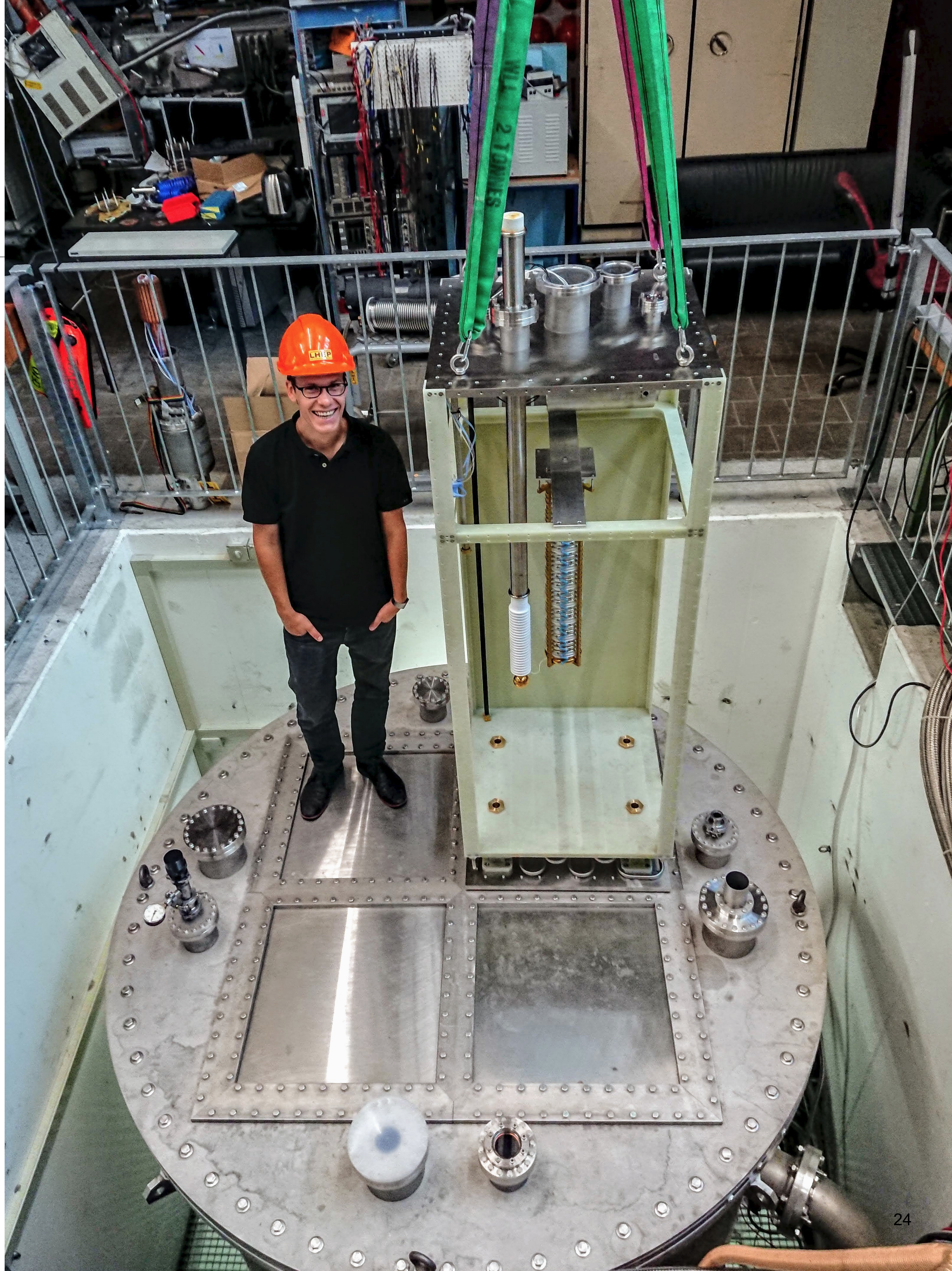
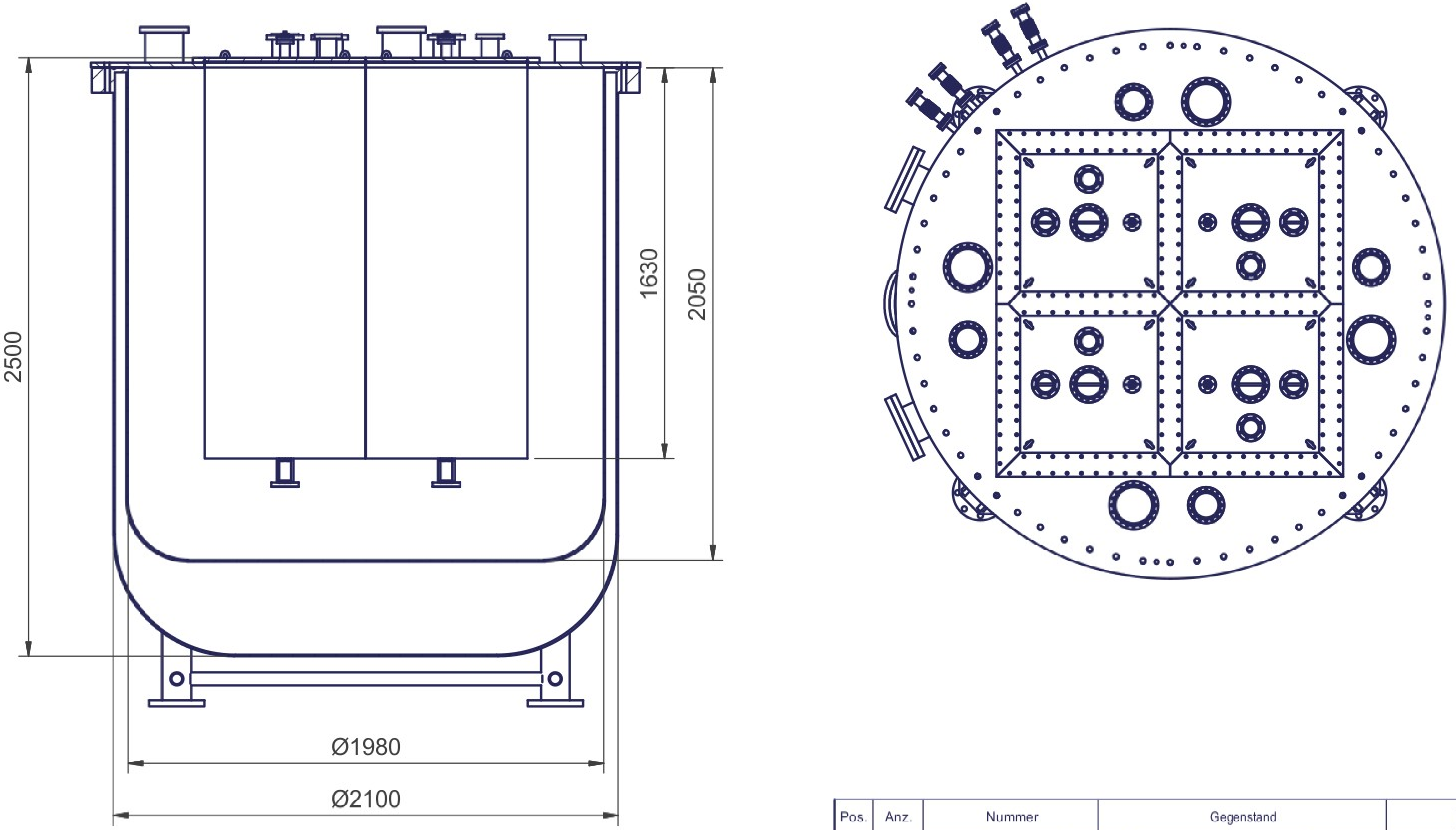




Vacuum insulated & LN2 cooled cryostat.
8.6 t total LAr.
1.7 t active LAr.

Pos.	Anz.	Nummer	Gegenstand	Material	Bemerkungen

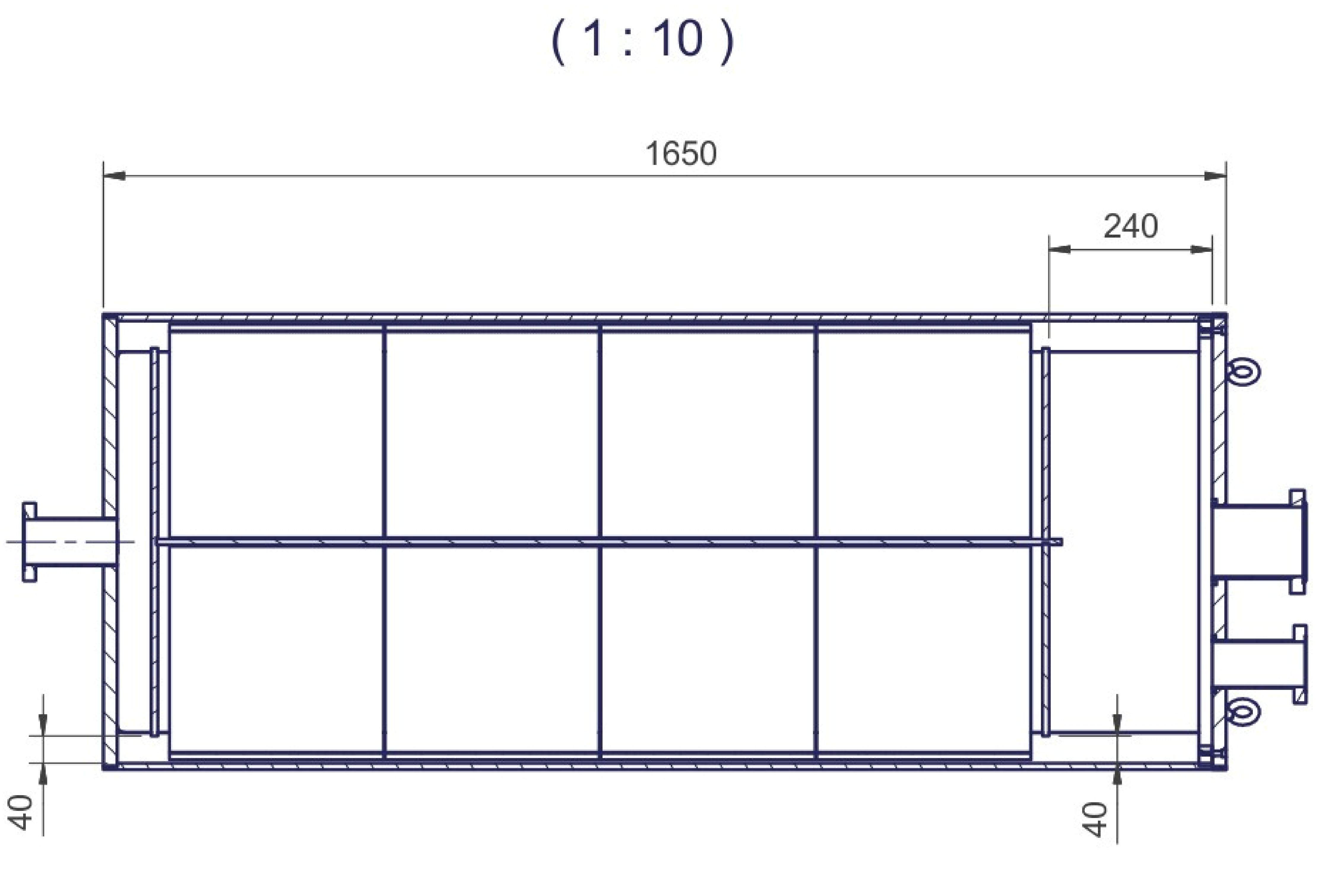
A3 | Datum | Name
Gez. | 11/28/2018 | rohaenni
Freig.
Gewicht:

LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

ArCube_2x2_assembly

Ausgabe | Blatt Nr. 1 von 1 | Massstab

Aus-gabe | Änderung | Datum | Name | Zusammenst. Nr.: | Ersatz für: | Ersetzt durch:



Module foot print 67 x 67 cm^2.
Drift length ~ 30 cm.
TPC height 1.3 m.


15
TON

Plans for 2x2 at FNAL

Focus on detector engineering

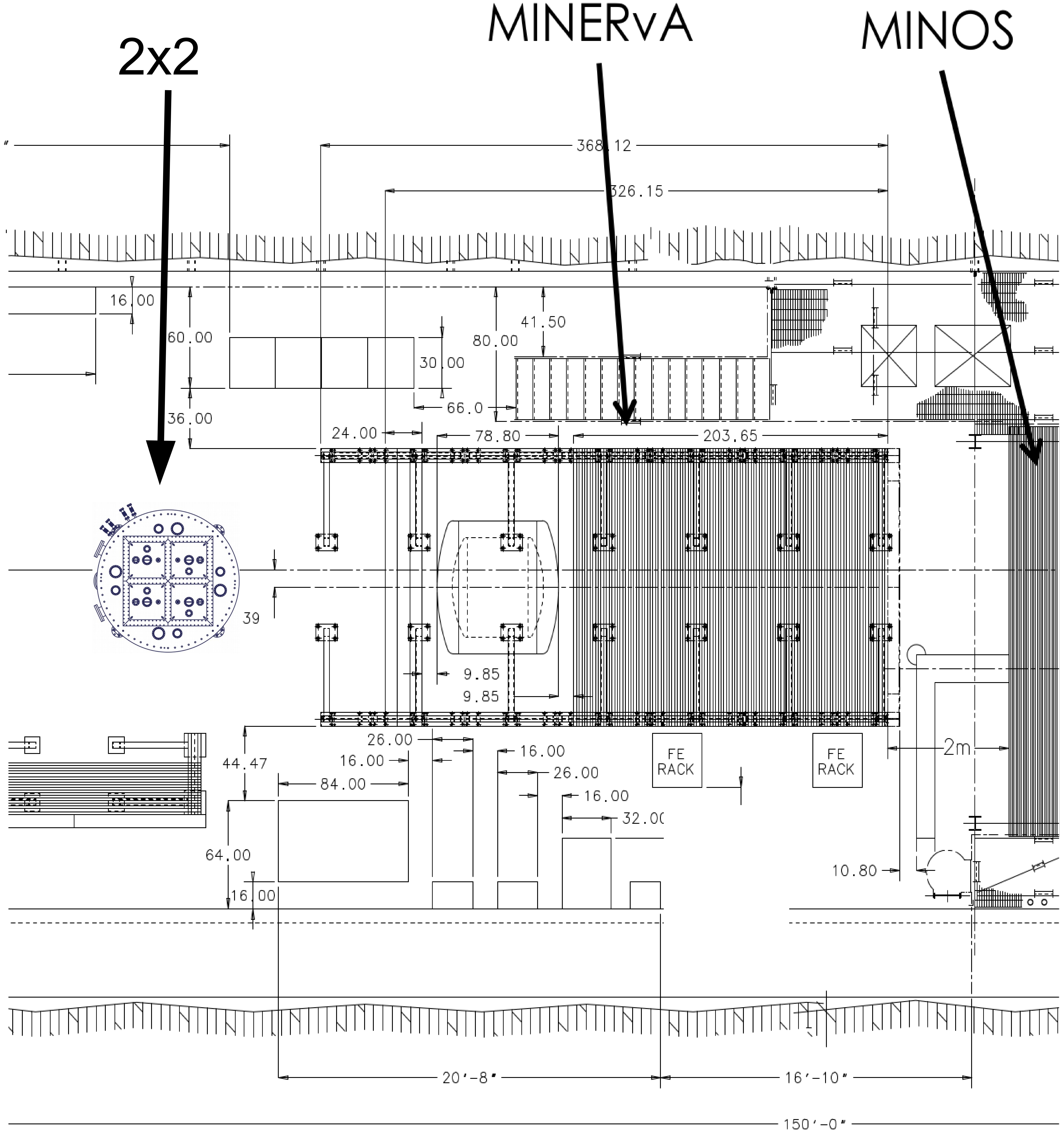
ND cryogenic prototyping/demonstration

Moveable TPC and ancillaries (ProtoPRISM)

Characterisation of detector response

Event reconstruction across modules

Core of ProtoDUNE ND

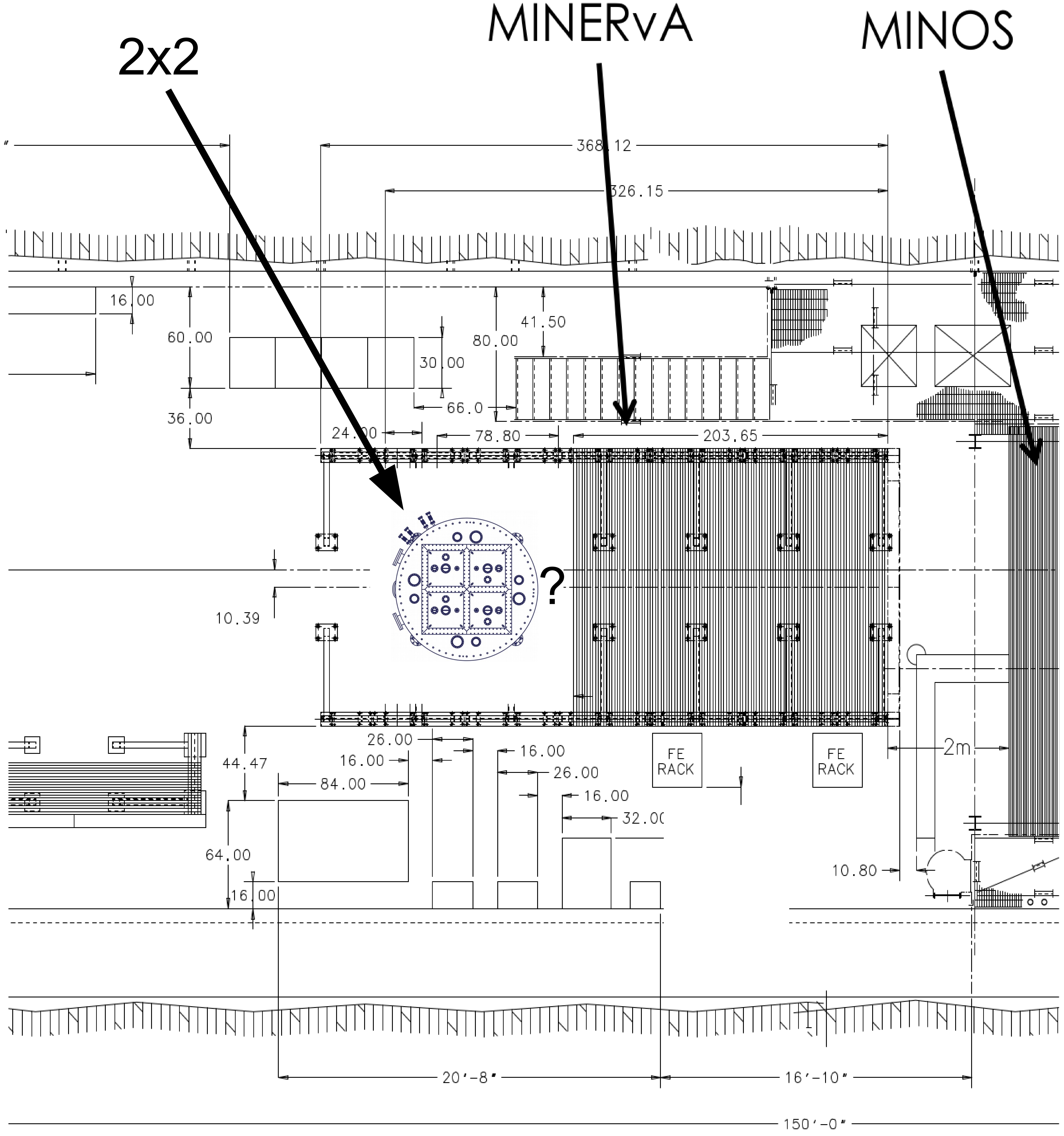


Plans for 2x2 at FNAL

Focus on detector engineering

- ND cryogenic prototyping/demonstration
- Moveable TPC and ancillaries (ProtoPRISM)
- Characterisation of detector response
- Event reconstruction across modules
- Core of ProtoDUNE ND

Location is still unconfirmed



2x2 Studies at FNAL

Combining light and charge readout.

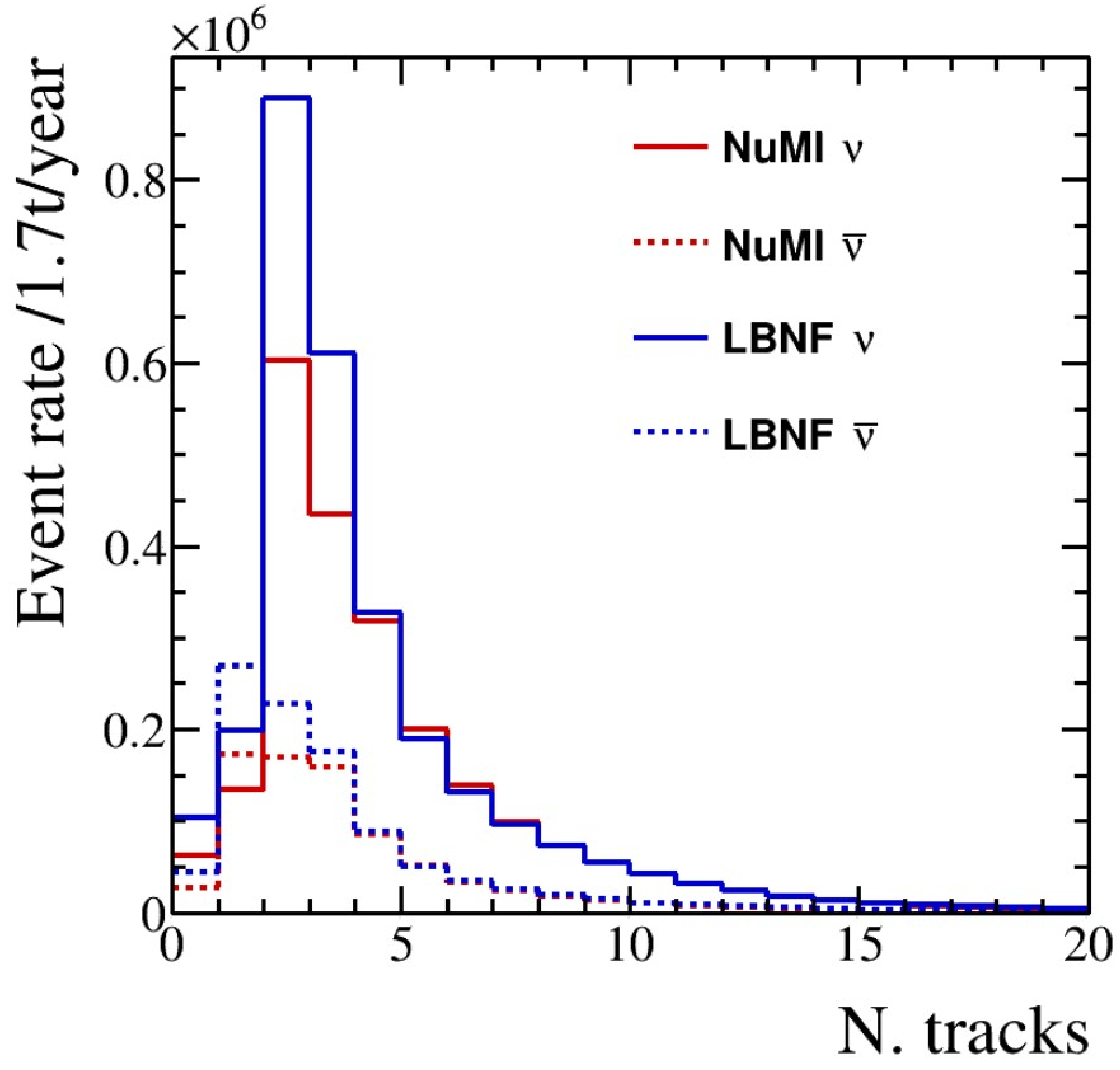
Reconstructing showers and tracks with charge sharing across modules.

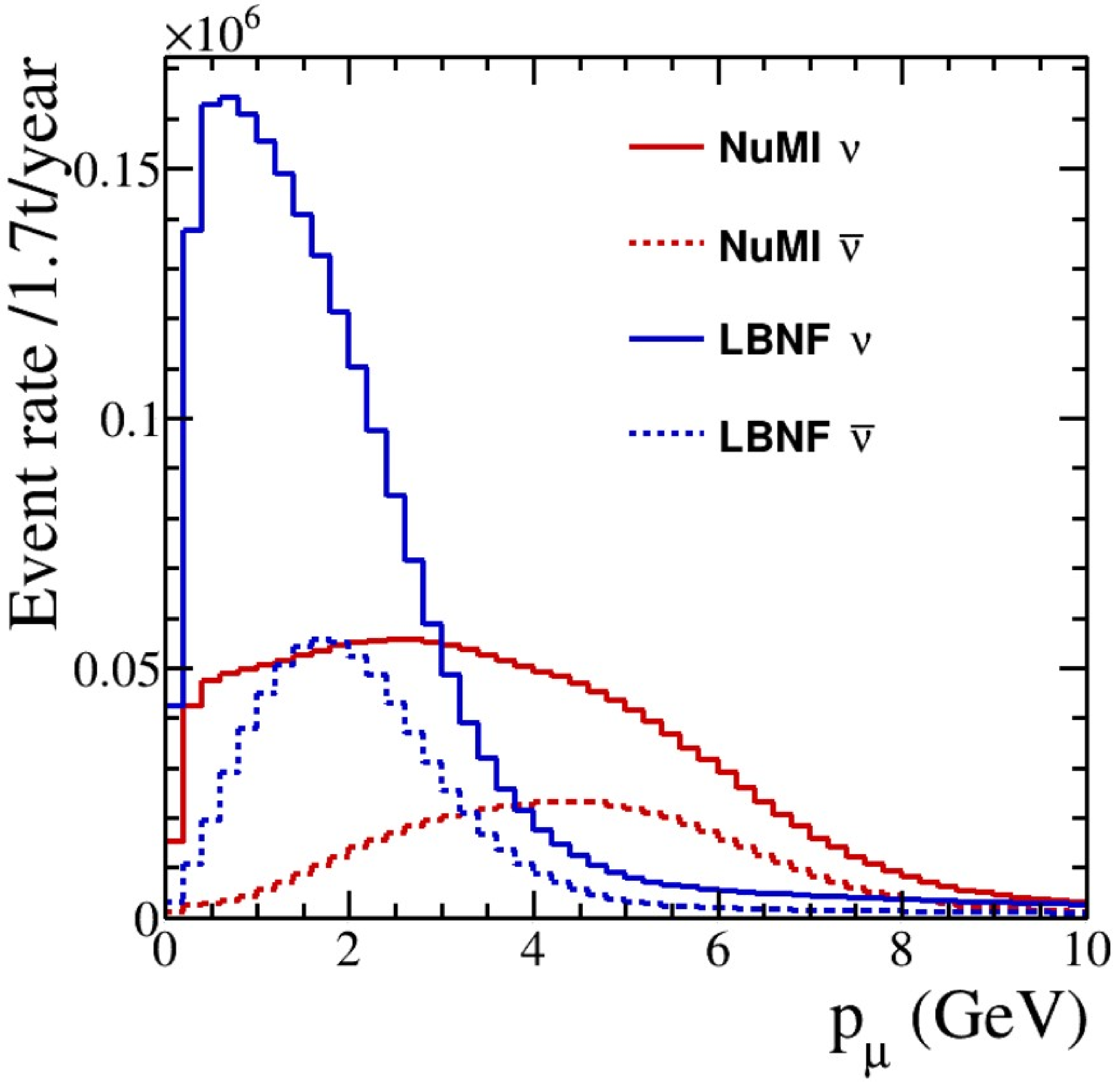
Reconstruction tests with complex event topologies.

Reconstruct contained showers for Pi0 peak.

Initial n-tagging studies.

2x2 Studies at FNAL





Expected yearly rates as function of number of MIPs, and muon momentum.

2x2, 1.7 t LAr volume for NuMI ME and LBNF beams.

GENIE v2.12.8 with "ValenciaQEBergerSehgalCOHRES" configuration.

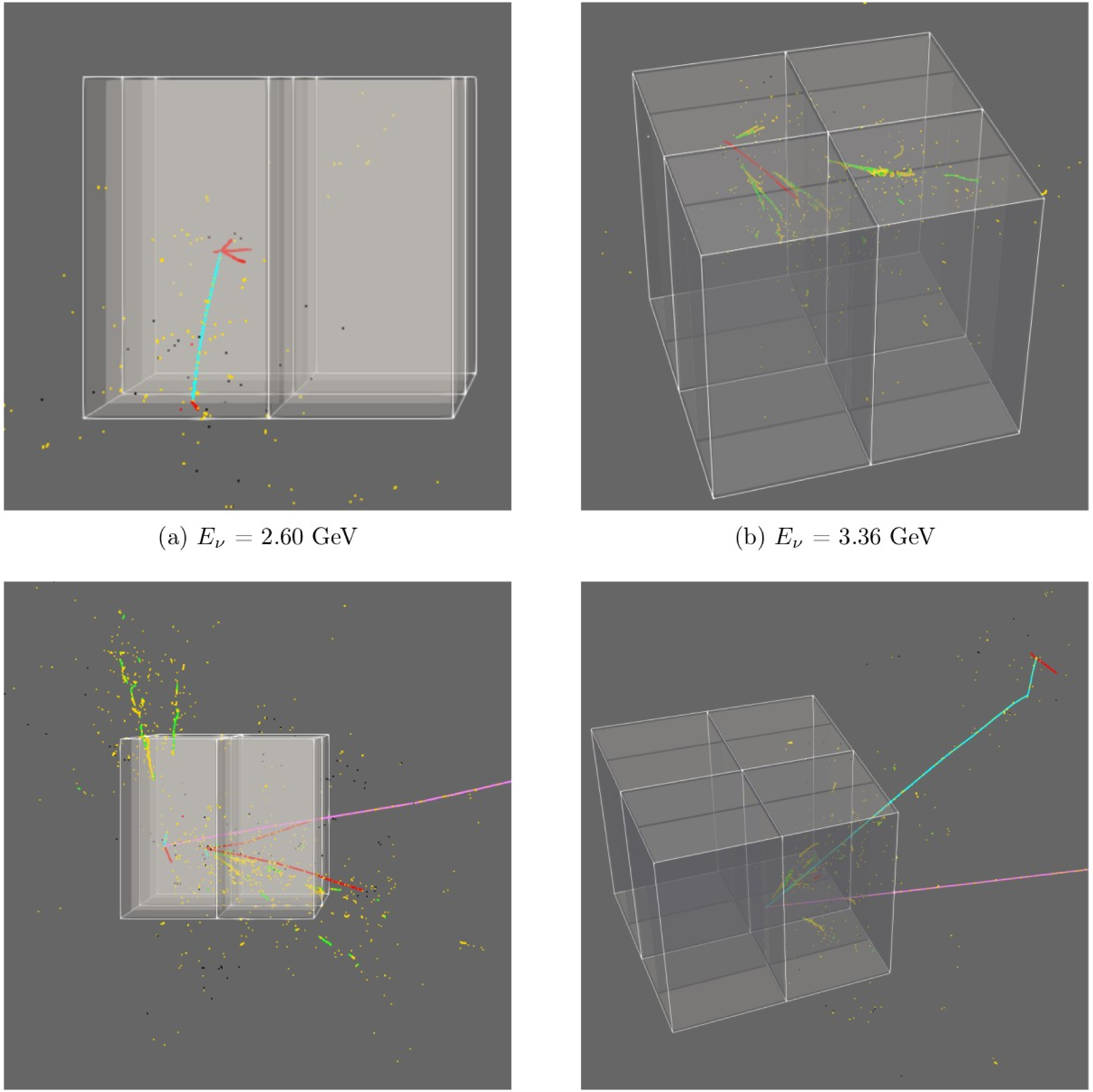
2x2 Studies at FNAL

Example νμ –argon ArgonBox simulated events for a number for different incident neutrino Energies.

$\pi^{\pm}$ blue; $\mu^{\pm}$ purple; e^{+} green;
e^{-} yellow; p red; N black.

Event vertices randomly placed within the 1.7 t active volume of the 2x2.

Geometry is superimposed, but not simulated by ArgonBox



(a) $E_\nu = 2.60$ GeV

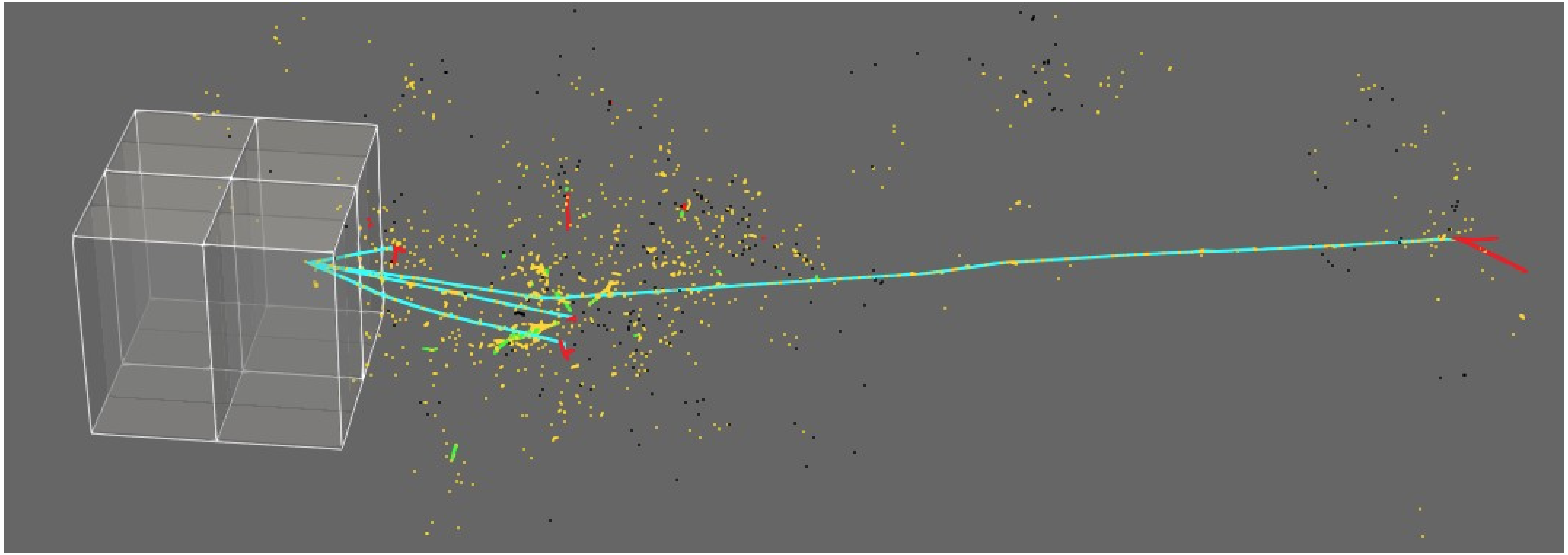
(b) $E_\nu = 3.36$ GeV

(c) $E_\nu = 4.83$ GeV

(d) $E_\nu = 9.37$ GeV

2x2 Studies at FNAL

Of course, there will be containment issues



(E_ν 8.17 GeV, cyan = pion, red = proton)

Towards the DUNE ND

ArgonCube has provided a novel LArTPC design that can function in a the DUNE ND.

There are still considerable challenges to face in scaling the various technologies.

The findings of 2x2 and ProtoDUNE-ND will dictate all aspects of the ArgonCube design for DUNE ND.

DUNE ND CDR 2019, TDR 2020, Installation 2025.